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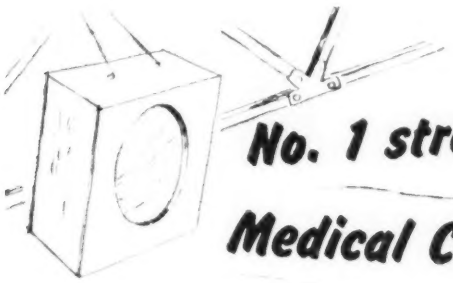

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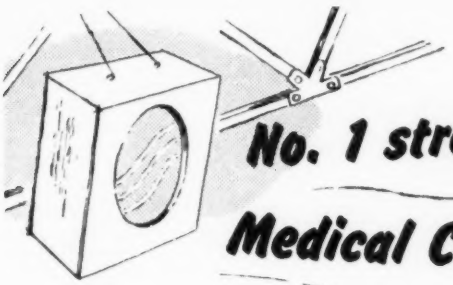

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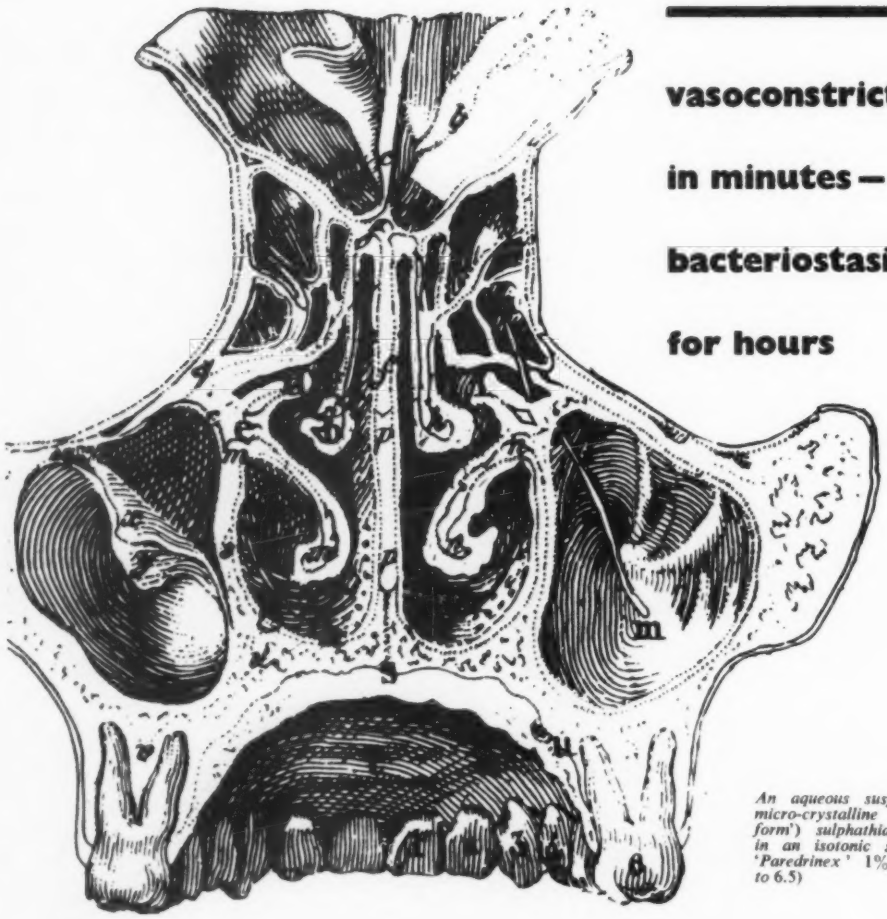

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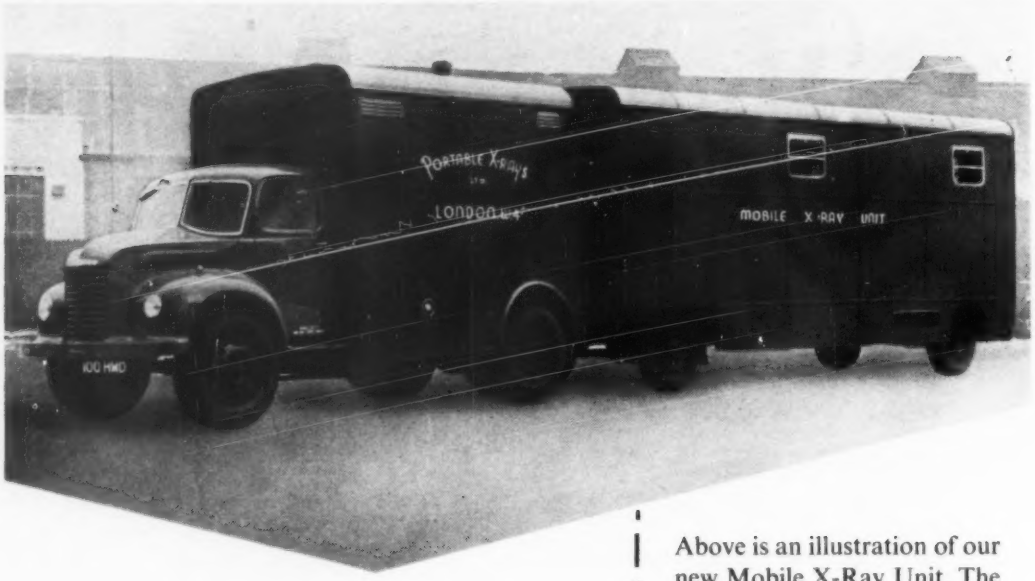

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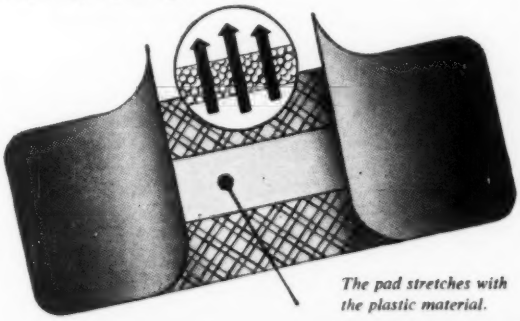

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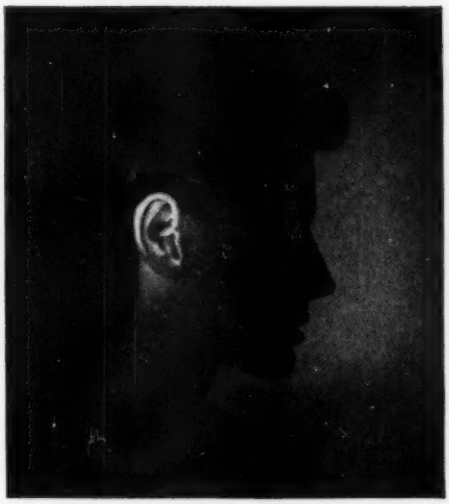

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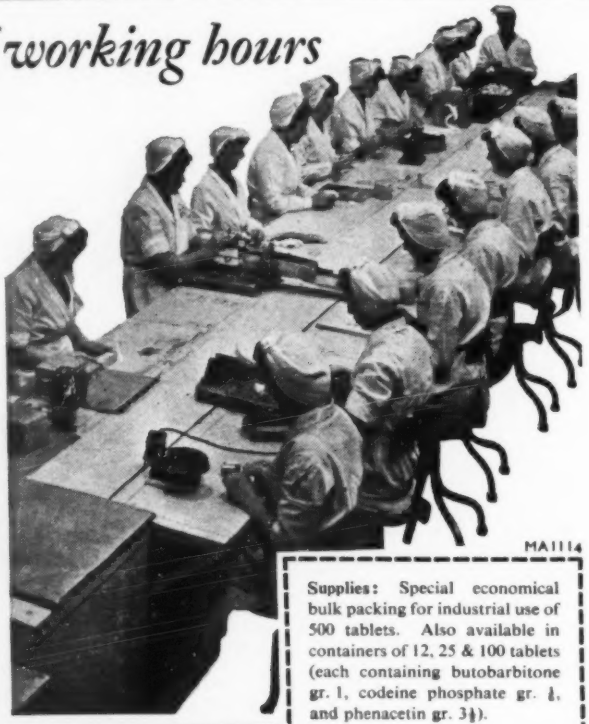

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Brit. J. industr. Med., 1957, **14**, 219.

EXPERIMENTAL STUDIES ON THE RELATIVE IMPORTANCE OF CONCENTRATION AND DURATION OF EXPOSURE TO DUST INHALATION

BY

B. M. WRIGHT

From the Pneumoconiosis Research Unit, Llandough Hospital, Penarth, Glamorgan

(RECEIVED FOR PUBLICATION JULY 13, 1957)

In a previous paper (Wright, 1953a) reasons have been given for believing that the best measure of the amount of inhaled dust that will be retained in the lungs is the product concentration × time. This conclusion was based on theoretical considerations of the mechanism of dust inhalation and retention, and on the experience of workers who have studied the correlation between dust exposure and the incidence of pneumoconiosis in men. It has frequently been suggested that the question should be studied experimentally, but no such experiments appear to have been recorded. Although the experimental approach to the question seems at first sight to be an obvious one, there are serious technical difficulties in exposing animals for sufficiently long periods to controlled dust concentrations, and in measuring their exposure. In this paper the way in which these difficulties have been overcome will be described, and an account given of three experiments designed to determine the relative importance of time and concentration in dust exposure.

Technique

Animal Exposure.—A brief account of the method of exposing animals for prolonged periods to controlled dust concentrations has already been given (King, Wright, Ray, and Harrison, 1950), but considerable technical improvements have been made since then, and the method is now well established. As the technique of experiments of this kind may have a considerable influence on the result it is necessary to describe it in considerable detail.

The basic principle of the method is to keep the animals in a cabinet and pass through it a stream of air to which dust is added at a controlled rate. The animals are normally exposed overnight for 20 hours (2 p.m. to 10 a.m.) for five days a week. This arrangement has the double advantage of using a high proportion of the rather short life-time of most experimental animals, and of making the routine care both of the animals and of the apparatus much easier, since about four hours of each working day are available for the purpose. As the exposures are often carried on for periods of a year or more, this routine care is of particular importance. So large a part of the exposure takes place at night when the cabinets are unattended that much care and thought have had to be given to certain technical features of the apparatus which are often neglected; these will now be considered in detail.

Exposure Apparatus.—The complete exposure apparatus comprises the following parts:

(1) Compressed air and vacuum supply
(2) Dust feed mechanisms
(3) Dusting cabinets

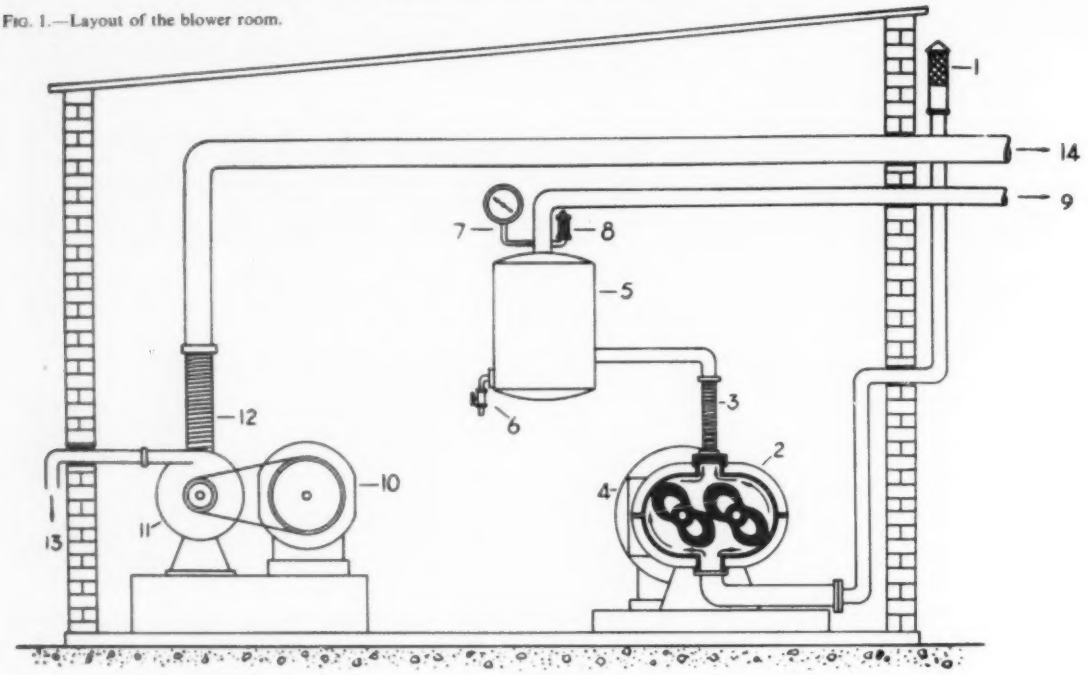
(1) *Compressed Air Supply.*—A clean and dry compressed air supply is absolutely essential, as impurities in the air are one of the commonest causes of difficulty in carrying out dusting experiments. The most common and important impurities are oil (with which most ordinary supplies are contaminated) and excessive water vapour, which may condense in the dust feed mechanism. A pressure of 10 to 15 lb./sq.in. is required, and the most satisfactory and economical source has been found to be a compressor of the Rootes type (Lucker, 1950) designed to operate without lubrication of the pumping chamber, so that it delivers completely oil-free air. The compressor is housed in an out-building, as it is rather noisy, together with the vacuum blower used for drawing air out of the cabinets. The general layout is shown in Fig. 1.

Air is drawn in through a filter (1) by the compressor (2) which is connected through a short length of rubber hose (3) (to reduce noise transmission) to a reservoir (5), which in turn leads to the compressed air main (9).

The reservoir smooths the air flow and also contains water-cooling coils (not shown) to remove excess moisture, which can be drained off periodically through the cock (6). The air pressure is adjusted by means of the pressure gauge (7) and blow-off valve (8) according to the amount of air required.

The vacuum blower (11) is of the centrifugal type and gives a vacuum of about 15 inches of water. Like the compressor it is connected by rubber hose (12) to the vacuum main (14) and its outlet (13) should preferably be on the opposite side of the building to the inlet of the

FIG. 1.—Layout of the blower room.



compressor. If suitably chosen and efficiently installed, both machines are capable of running for years without any attention except periodical oiling and greasing.

(2) *The Dust Feed Mechanism.*—This mechanism has been described in detail in a previous publication (Wright, 1950) and its form has remained the same, with only minor improvements and modifications. Its fundamental principle consists of using dust compressed into a cake, and feeding it by a micrometer device against a cutting edge which scrapes a very thin layer off into the air stream. The dust concentration can be varied by adjusting the rate of feed, and any desired level reached by trial and error. Once the appropriate feed rate has been found, the dust concentration can be kept at the same average level indefinitely, so long as the dust used remains of the same size distribution. The present form of the instrument is shown in Fig. 2.

(3) *The Dusting Cabinets.*—These are similar to those previously described, the main modification being that the pyramidal top has been truncated. The general

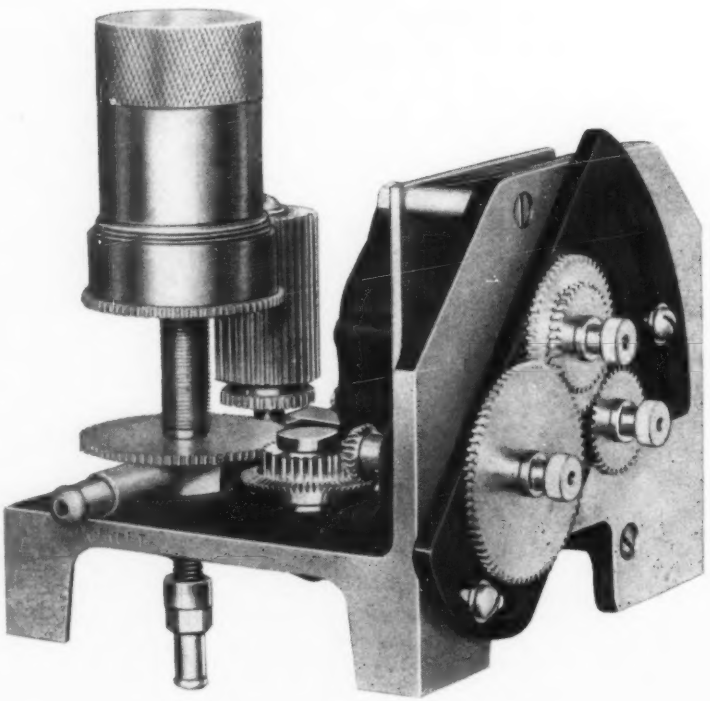


FIG. 2.—The Wright dust feed mechanism.

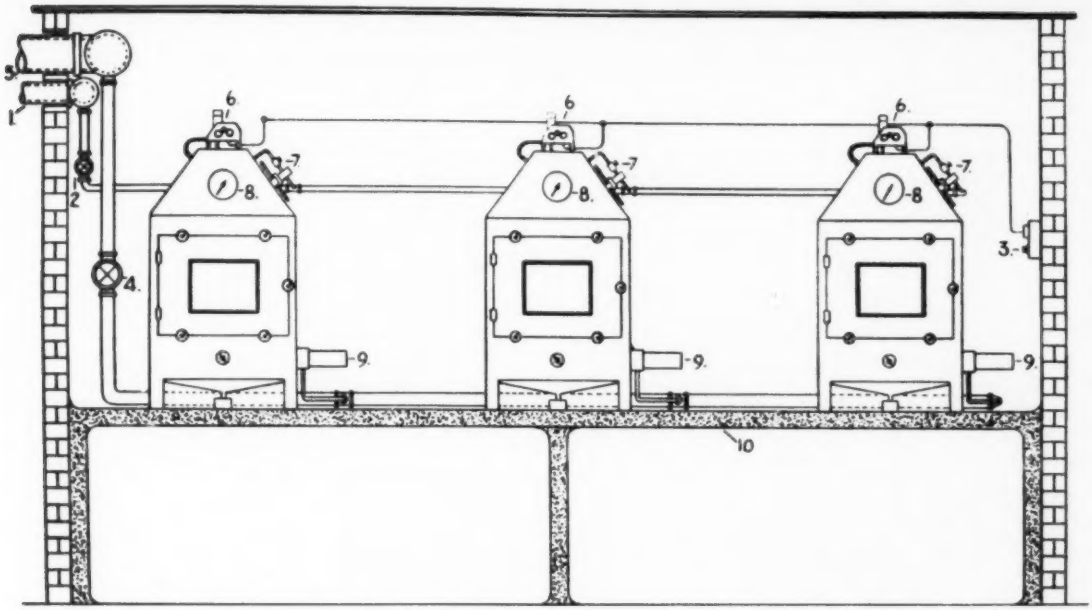


FIG. 3.—General arrangement of the dusting cabinets.

arrangement of the cabinets is shown in Fig. 3.

The cabinets (Fig. 4) are made of sheet metal with glass or perspex windows. The door is sealed with sponge rubber, and secured by means of " burglar proof " type window catches (not shown). The cabinet is not completely airtight, so arrangements are made to ensure that the pressure within it is always very slightly below atmospheric, to minimize the leakage rate and prevent dust escaping into the room. This is done in the following way: air is drawn from the cabinet through the orifice (15) at the bottom and through the Soxhlet thimble filter (16) to the vacuum main (19). The rate of flow through the filter is considerably greater than the rate of flow into the cabinet, but the excess air is drawn in through three large bypass holes (18) so that the suction head that is applied at the orifice (15) is negligibly small. The system works well, so long as the dust concentrations used are not so high that the filter clogs and reduces the output rate below the input rate in less than 20 hours.

Because of the danger of the animals asphyxiating if the air supply fails (*e.g.*, during a power cut) each cabinet is fitted with a spring-loaded safety hatch (4) which is normally held closed by the compressed air pressure, but opens if it fails.

The air flow into the cabinet through the dust feed mechanism (9) is controlled by the valve (5) and flow meter (6) (made from an air speed indicator).

The rate of air flow was originally fixed by reference to the ventilation rate of the animals. According to Guyton (1947) the minute volume of an average rat is about 100 ml., so a group of 20 rats would breathe 2 litres/minute. In order to keep the carbon dioxide level in the cabinets at a reasonable level, a volume considerably greater than this is required, and a figure of 10 litres/minute was chosen. This keeps the carbon dioxide level at about 1%.

The animals (usually rats) are kept in open cages 20 in. × 20 in. × 9 in. which will accommodate up to 20 young rats. The cages have mesh bottoms and rest on runners, with a removable tray for droppings below. Food and water are provided in excess, and " cannibalization " of dead animals is thus kept to a low level, though unfortunately not entirely eliminated. The general health of the animals is good; the exposed ones often live longer on the average than their unexposed fellows, when in moderate concentrations of inert materials such as coal dust, possibly because of the uniform air-conditioned environment in which they live.

Measurement of Dust Exposure.—In experiments of mainly pathological interest, such as that described by King *et al.* (1950) it has been found sufficient to take some preliminary measurements with a thermal precipitator and adjust the mechanism until the desired concentration level is obtained. It can be assumed that this concentration has been maintained at about the right level all night, so long as the air flow is still within 10% of the proper level, and the dust feed mechanism is still running freely next morning. A snap check is usually made an hour after starting, and before stopping exposure in the morning, with a simple filter paper stain device. This has no pretensions to accuracy but guards against human errors such as forgetting to switch on a mechanism.

For the purpose of the particular experiments to be described, a more reliable and accurate method was required, and therefore a long-term continuous sampler

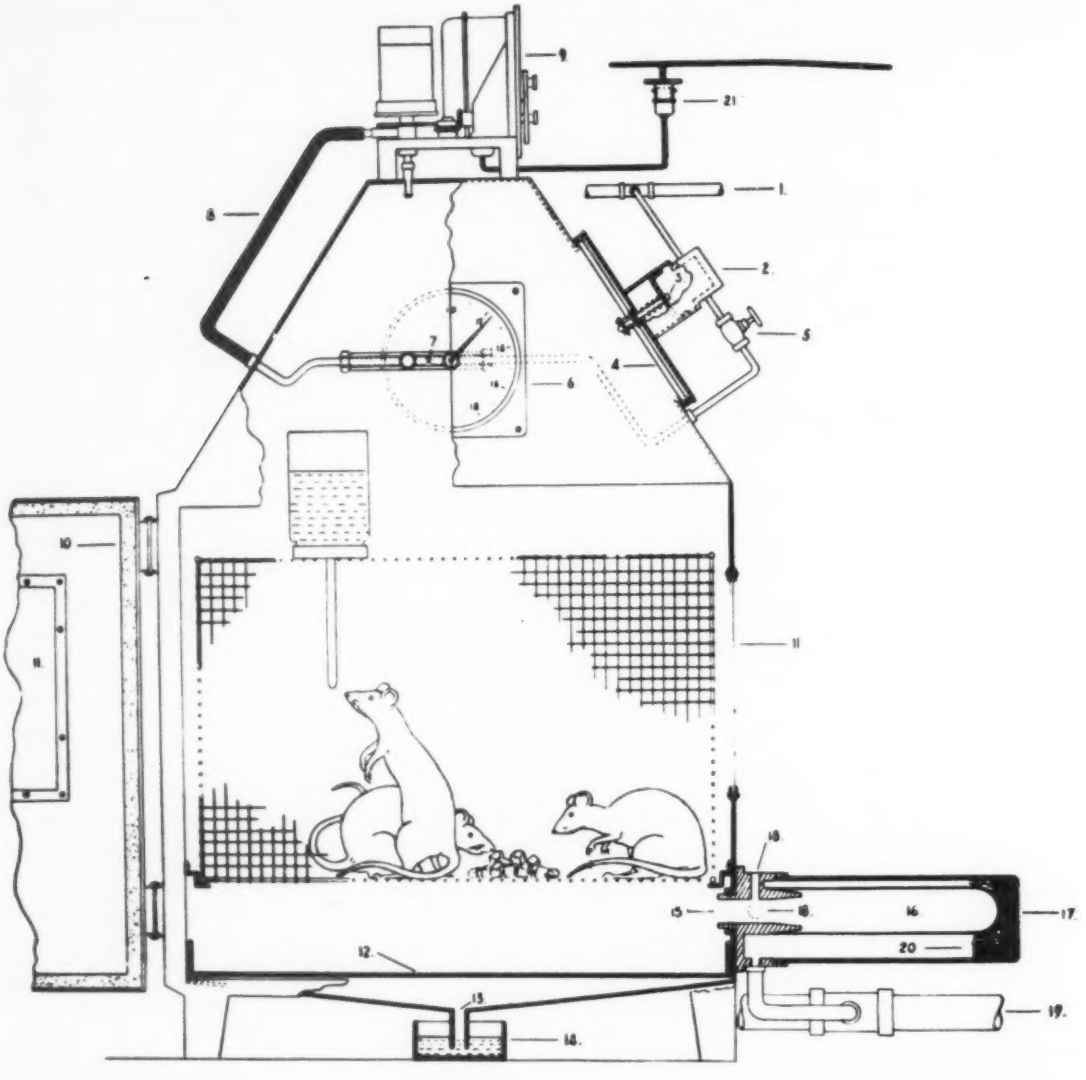


FIG. 4.—Detail of a dusting cabinet.

was developed. This consisted of a gravimetric thermal precipitator (Wright, 1953b) through which air was drawn from the cabinet at 100 ml./minute (approximately the minute volume of a rat), and which deposited the dust on an aluminium plate on which quantities of the order of 7 mg. could be easily weighed with sufficient accuracy.

Gravimetric sampling is not a satisfactory method of measuring dust exposure unless precautions are taken to exclude from the sample particles and aggregates too large to be retained in the lungs. Such particles and aggregates may be present to a variable extent, and may constitute more than 50% by weight of the airborne dust, even when the cloud is produced from material which is all nominally within the "respirable" size range (see Wright, 1953a). Some form of size selector must therefore be fitted to the intake of the sampler to prevent particles outside the respirable range from reaching the collecting plate. In the first experiment to be described the sampler was fitted with a rather crude and unsatisfactory cylindrical elutriator, but in later experiments a simple horizontal duct of the type specified by Hamilton and Walton (1952) was used. This was made by flattening a piece of thin-walled brass tubing to give a duct 1 mm. high, 1·5 cm. wide, and 7·3 cm. long. The floor area of 10·96 cm.^{2} gives a theoretical cut-off of 50% of 5μ diameter spheres of unit density at a flow rate of 100 ml./minute. Tests with a glass sphere cloud (Wright, 1954) showed good agreement with the theory. The reasons for

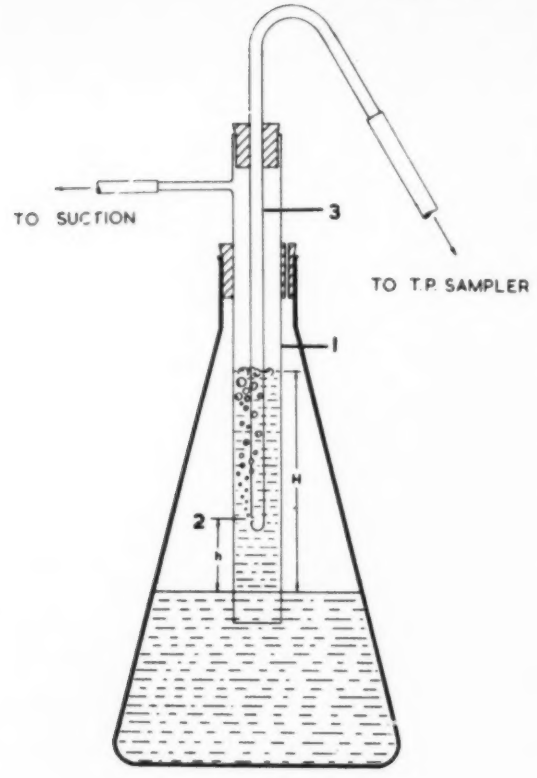


FIG. 5.—Constant-level suction device.

choosing this cut-off and the question of its suitability will be discussed later.

This simple elutriator was found to work satisfactorily, except for a tendency to clog at the mouth, where the large particles and aggregates accumulated. The mouth was, therefore, belled in a vertical plane, which is permissible since the height of the duct is immaterial (Hamilton and Walton, 1952) and this overcame the difficulty.

The control of the flow through the sampler was fairly critical, since not only was the aspirated volume calculated on the assumption of a constant flow, but also variations in the flow rate would affect the cut-off, and consequently the mass concentration of the dust penetrating to the thermal precipitator. Suction was therefore taken from the vacuum main, which was subject only to small long-period variations, and stabilized by means of the hydrostatic constant head device shown in Fig. 5. Provided that the diameter of the inner tube (1) is small compared with that of the flask and that the loss of water by evaporation is negligible, variations in the available suction head (H) will not affect the effective suction head (*h*), because the head of water above the orifice (2) exactly cancels the difference between *H* and *h*. Of course, *H* must never at any time fall below *h*, but this is easy to arrange. The effective suction head *h* can be adjusted by sliding the inlet tube (3) up and down in the cork. With a head of about 20 cm. water, a flow of 100 ml./minute is given by an orifice about 0·25 mm. in diameter. Such a small orifice would normally be liable to clog, but since the air passing through it has all passed through the thermal precipitator it is completely free of dust, and the flow can be maintained constant within 5% for 20 hours quite easily. The flow was adjusted and checked with a rotameter at the beginning of each exposure, and again at the end. The rotameter itself was made in the laboratory and calibrated with a bubble flowmeter.

Plan of Experiments

The general plan of all the experiments was the same; two groups of rats were exposed in the same cabinet, one (A) for the usual 20-hour period overnight, and the other (B) for two hours in the morning. Before starting the actual exposure experiment, the dust feed rate was adjusted so that the dose administered, as measured with the sampler, was the same in both cases; *i.e.*, the dust concentration in the short period B was 10 times that in the long period A.

The two doses were measured daily, and the total doses summed up from day to day. If the difference between the total doses exceeded one day's dose, either one mechanism was adjusted or an occasional exposure was missed, so as to keep the totals as close as possible. The daily dose averaged about 7 mg., varying from 4 to 10 mg. on occasions.

At the end of the experiment all surviving animals were killed at the same time, within a few days of the end of exposure, and the dust was extracted from their lungs and weighed. It was expected that there would be some variation in the amount of dust in the lungs in different animals within the same group, which would be likely to be to some extent correlated with their body weights, so all the animals were weighed at the beginning of the experiment, identified by ear-punching, and weighed again at the end. As will be seen, this precaution was well worth while as the correction for body weight, using covariance analysis (Fisher, 1934), considerably reduced the scatter.

Results

Experiment I.—Two groups of 14 young male rats were exposed for five days a week over a period of three months. One animal in Group A was accidentally killed, but otherwise both groups survived to the end of the experiment. Ten animals in each group were used for dust extraction, the lungs of the remainder being examined histologically. The dust used was " levigated alumina ", a form of synthetic alumina (Al_2O_3) made for fine grinding and polishing. This was chosen as being readily available and known to be of very low solubility and pathologically inert, and at the same time easily estimated in the lungs by simple ashing. Although this method of estimating the lung dust was used initially, it was eventually decided to estimate the Al_2O_3 content of the ash chemically, so as to eliminate possible

TABLE 1
RESULTS IN EXPERIMENT I

Group A (503 mg. at low concentration, long exposure)			Group B (503·6 mg. at high concentration, short exposure)		
Body Weight (g.)	Al_2O_3 (mg.)		Body Weight (g.)	Al_2O_3 (mg.)	
	Uncorrected	Corrected		Uncorrected	Corrected
235	67·2	79·0	255	58·3	63·2
245	69·3	77·7	255	49·1	54·0
260	74·5	77·7	285	55·0	49·7
295	76·2	67·5	290	59·7	52·7
300	78·3	67·9	280	59·2	55·6
254	80·2	85·5	280	65·4	61·8
255	63·0	67·5	250	46·7	53·4
270	70·0	69·8	325	84·1	65·1
235	53·9	65·7	305	68·3	56·1
260	78·2	81·4	255	41·7	46·6
Mean	71·1	74·0		58·7	55·8
S.D.	8·2	7·1		12·1	5·9
Coefficient of variation	11·5%	9·6%		20·6%	10·6%
Percentage retention		14·7			11·1

errors caused by the need to make an allowance for the " intrinsic " lung ash.

Although the animals were weighed both at the beginning and end of the experiment, it was found that either weight could be used for " correction ", so the dead weight was chosen because it was rather more easy to determine accurately.

The dose of dust administered to both groups, as measured by the sampler and the amounts found in the lungs of the rats (estimated chemically as Al_2O_3), are given in Table 1.

The following points may be noted at this stage:—

(1) The effect of correcting for body weight is to reduce the scatter of the results from 11·5% to 9·6% in Group A, and from 20·6% to 10·6% in Group B.

(2) The animals in Group A retained 14·7%, and in Group B 11·1% of the dust collected by the sampler.

(3) The ratio between the average amount of dust retained by the animals in Group A and those in Group B is 1·325 (95% confidence limits 1·20—1·47).

Experiment II.—This was a repetition of Experiment I, except that, as mentioned earlier, a different type of size selector was fitted to the sampler and also a different technique was used for extracting the dust from the lungs. It was found that Al_2O_3 could be easily and quantitatively extracted from the lungs by a technique which had been used for extracting coal dust. This technique, which has been developed by Mr. T. J. H. Cooke, is given in the Appendix.

During the experiment the original supply of " levigated alumina " ran out, and the new supply, obtained from the same makers, was found to be considerably coarser. For this reason it was necessary to run the experiment for two months longer, and the dose of 500 mg. obtained in the first experiment could not be reached. Two groups of 10 animals were used, and they all survived to the end of the experiment.

The results are given in Table 2.

TABLE 2
RESULTS IN EXPERIMENT II

	Group A	Group B
Exposure	Low concentration	High concentration
Dose	427 mg.	440 mg.
Weight of dust in lungs (standardized for body weight)	32 mg. (S.D. 5·8 mg.)	23 mg. (S.D. 2·7 mg.)
Percentage retention	7.5	5.2

Owing to a technical error the exposure of the two groups was slightly different so that the comparison between them can only be made on a percentage retention basis. On this basis the ratio A/B is 1·37 (confidence limits 1·13—1·66). This ratio is very close to that found in the first experiment (1·325). On the other hand, the percentage retention is only about half that observed in the first experiment. This difference may have been partly due to the change in the size distribution of the dust, and partly to the change of size selectors. A comparison between the new and old size selectors showed that the new one cut off about 10% more, by weight, than the old. Owing to the unsatisfactory nature of the old size selector this anomaly was not further investigated, but the question of size selection and the effect of size distribution will be considered again later.

Experiment III.—The first two experiments were open to criticism on the ground that the concentrations used, even in the " low " concentration cabinet, were considerably higher than those commonly

found in human exposure, being about 60 mg. per cubic metre in the A experiment, and 600 in the B. Comparable figures, using a basically similar size selecting sampler in a moderately dusty coal-mine, would be 20 mg./cu.m. (Wright, 1954). A third experiment was therefore carried out in which the two groups were exposed to much lower concentrations, the dose used in the previous experiments being administered in a week instead of a day, and the experiment being carried out for 18 months instead of three and five months, thus reducing the dust concentrations by a factor of about 5.

It was also decided to use coal-dust instead of levigated alumina for a number of reasons:—

(1) The original reason for using alumina—its ease of estimation chemically or by ashing—was no longer important since a dust extraction method was being used.

(2) Our accumulated experience with a variety of coal dusts and other purer forms of carbon suggested that coal-dust was pathologically as inert as alumina and was therefore equally suitable for use in long-term experiments where any kind of specific pathological response was undesirable as it would confuse the issue.

(3) A device, the " turbine grinder ", for producing large quantities of fine coal-dust of constant size distribution had already been developed (Wright, 1953c) and so a steady supply of dust for the whole experiment could be assured.

For these reasons " turbine ground " steam coal was used and the concentration was adjusted so that the dose given in each experiment was about 7 mg. in five days. The gravimetric thermal precipitator with a horizontal elutriator was used exactly as in Experiment II, except that the samples were weighed only once a week instead of daily.

The experiment was started on July 26, 1954, and ended on December 30, 1955. As was to be expected in an experiment of this long duration there were occasional breakdowns, and some casualties among the animals. In particular, five of Group A died early in the experiment from an infection, and three of Group B died near the end of the exposure. It was noticeable that the Group B animals were less healthy than those in Group A; most of them lost weight towards the end, and at necropsy much more bronchiectasis was found among them than in Group A. Apart from this, no difference in the histological appearances between the two groups was noted in this or in either of the two previous experiments. Although it is tempting to attribute this difference in health to the difference in dust exposure, there is in fact another explanation for which there is supporting evidence. The Group B animals only spent two hours a day in the cabinet, while the Group A were in it for most of their lives. The latter were therefore in the uniform sheltered environment and conditioned air which, as already noted, seems to have a beneficial effect on the health of the animals, while the former were not, and this could completely account for the difference.

A number of mechanical breakdowns also occurred, but by suitable adjustments of the dust feed rate it was possible in the end almost to equalize the doses of the two groups.

Eighteen young male rats were used in each group, chosen by random numbers from a single group of 36. Of these 11 survived to the end of the experiment in Group A, and 12 in Group B. All the animals were earmarked and weighed at the beginning of the experiment and weighed again at three-monthly intervals, and at death. Two animals in each group were used for histological study; the results for the remainder are given in Table 3.

TABLE 3
RESULTS IN EXPERIMENT III

	Group A	Group B
Exposure	Low concentration	High concentration
Dose	444 mg.	446 mg.
Weight of dust in lungs (standardized for body weight)	97·4 mg. (S.D. 15·2 mg.)	82·5 mg. (S.D. 12·9 mg.)
Percentage retention	22	18·5

The body weight used for standardization was the average of the three-monthly weights up to and including the maximum weight reached.

The ratio of the percentage retentions is 1·18 (95% confidence limits 1·07—1·31). Although this ratio is rather smaller than those found in the two previous experiments it cannot be said that it is significantly different.

Discussion

The immediate conclusion that can be drawn from these experiments is that, under the described conditions, a very large difference in the concentration and duration of exposure produced a relatively small difference in the amount of dust accumulating in the lungs. The further conclusion, that a high-concentration, short-duration exposure produced from 20% to 30% less effect, is somewhat more doubtful as its validity depends on the assumption that the sampling instrument was giving a true measure of the amount of dust that would be retained in the lungs. This in turn depends on the assumption that its size selector had filtration properties similar to those of the upper respiratory tract of rats, so that the dust penetrating to the thermal precipitator would be similar in size distribution to that which

would be deposited in the alveoli. Although a certain amount of information is available about the filtration properties of the upper respiratory tract in both men (Davies, 1949; Wilson and La Mer, 1948) and animals (Shoshkes, Banfield, and Rosenbaum, 1950; Palm, McNerney, and Hatch, 1956) none of this information enables the size-selecting characteristics of the respiratory tract to be specified with any great accuracy. From a practical point of view, in fact, as much useful information can be derived by studying the dust obtained from the animals' lungs and noting that, like the dust extracted from human lungs, it contains very few particles indeed over about 7μ average diameter. It was for this reason that it was decided to use the standard elutriator specified by Hamilton and Walton. This has no pretensions to simulate, except in the most general way, the size-selecting characteristics of the upper respiratory tract, but it has the great merit of being easily specified theoretically, and reproduced mechanically. At the same time it separates particles by the same physical mechanism as operates in the respiratory tract, and gives a cut-off at about the same level.

Unfortunately it can be shown theoretically, and has been found experimentally, that the weight of dust collected by a sampler fitted with a size selector will vary considerably according to the cut-off level chosen, and also that the amount of this variation will differ with clouds of different size distribution.

If, therefore, the size selector used was in fact very different in its properties from the upper respiratory tract of the rats, the difference in the amount of dust retained by the two groups of animals might be accounted for, wholly or partly, by a difference in the size distribution of the high and low concentration clouds. Such a difference might well be present, due to more aggregation occurring in the high concentration cloud.

Experimental.—To investigate this question some sampling studies were made to see the effect of using size selectors with different characteristics in the two types of experimental cloud. The sampling was carried out exactly as in the main experiment, and a group of animals was left in the cabinet so that any effects of heat and humidity on the size distribution of the cloud would be reproduced.

Two gravimetric thermal precipitators were used, one fitted with the standard size selector having a cut-off of 50% at 5μ diameter, and the other with a longer elutriator of the same pattern having a cut-off of 50% at 3μ diameter.

Sampling was first carried out in the aluminium oxide clouds. As was to be expected, the dose measured with the 3μ selector was smaller than that measured with the 5μ selector, but in addition the difference was greater in the B cloud than in the A. Had, therefore, a 3μ elutriator been used instead of a 5μ, the dose given to the two groups would have been found to be different. Expressed as a ratio A/B this difference was 1·20, which might therefore account partly for the difference in the percentage retention of the two groups.

Similar studies were then made in the coal-dust clouds taking weekly instead of daily samples. The results were similar, but the difference between the two clouds was smaller, the ratio being only 1·03. This again could account for a small part of the difference in retention of the two groups of animals.

In both cases only 15 sets of samples were taken and there was sufficient scatter to prevent the observed difference being significant at the 5% level; as both studies showed a difference in the same direction, which was also that expected, it is probable that a sufficiently prolonged trial would establish a significant difference eventually, but in view of the small magnitude of the difference such a trial seemed hardly worth while, especially in the coal-dust clouds, where only one sample a week could be obtained. For the same reason direct studies of the size distributions by microscopy were not carried out because it was felt that the results might well be ambiguous and not worth the trouble involved.

It seems likely that the use of a size selector with an even lower cut-off than 50% at 3μ might further increase the difference between the dose measured in the two clouds, but it is hard to see how the use of such a size selector could be justified on the available evidence. Probably the best data are those of Shoshkes *et al.* (1950) who found that the mass median diameter of corn oil droplets (density 0·9) penetrating to the alveoli of mice was 2·9μ, the maximum observed diameter being 6μ. Some experiments of my own, using glass spheres (density 2·25), gave very similar results, the cut-off, for a variety of animals, including mice, rats, cats, rabbits, and a small monkey, being at about 4μ, which is equivalent to 6μ at unit density.

A horizontal elutriator with a cut-off of 50% at 3μ has a cut-off of 100% at 4·25μ, which on this evidence at least is already a good deal too low, and the standard elutriator with a cut-off at 7·07μ is nearer the mark.

It may be concluded therefore that at best only a small part of the difference in dust retention by the two groups could possibly be accounted for by the use of an inappropriate size selector on the sampler, and that most of the difference must be considered real.

It is possible to speculate at length on the physiological mechanisms which might account for the difference in retention between the two groups, but since this difference is small compared with the difference in the type of exposure it would be profitless to do so. One possible explanation that might

be advanced is that the high incidence of bronchiectasis in the B group might have led to the loss of dust in the exudate. Since, however, bronchiectasis of any degree was only observed in the long-term experiment, in which the difference in retention between the two groups was least, this seems an unlikely explanation.

It is tempting to attribute the marked increase in the percentage retention in Experiment III, as compared with that in I and II, to the more prolonged exposure to lower concentrations, but it may equally well have been due to a difference in the size distribution of particles in the dust clouds.

A further point of interest is that the reduction in the dose that would be produced by the use of a 3μ elutriator would only double the percentage retention, so that no conceivable elutriator could bring it up to 100%. This is, of course, to be expected on two grounds. First, all the available evidence suggests that the alveolar retention of the most penetrating particle size, about 1μ, is only 50%; and second, an unknown proportion of particles which penetrate to the alveoli may be subsequently removed by phagocytes and transported to the ciliated epithelium and so out of the lung.

It is obvious, however, that much more needs to be done to establish the pattern of the relationship between dust exposure and retention. The main object of this paper has been to show how such investigations can be carried out, and to stimulate others working in the field to explore this part of it.

Summary

Details are given of an experimental technique for exposing groups of animals for long periods to the inhalation of dust clouds of controlled concentration, and of a method of measuring their average exposure.

Three experiments are described in which two groups of rats were exposed to the inhalation of dust, one group being exposed for 20 hours a day and the other for two hours to a concentration 10 times greater, so that the two groups both received the same daily dose.

In the first two experiments the animals were exposed to relatively high concentrations of aluminium oxide dust over a period of a few months, and in the third to moderate concentrations of coal dust for 18 months.

In all three experiments the amount of dust retained by the two groups was very similar, but the high concentration group always retained rather less (20-30% less) than the low concentration group.

The validity and implications of these findings are discussed.

The techniques and experiments described have been evolved and carried out over a period of about 10 years and it is impossible to acknowledge the assistance of all those who have taken part in the work.

I should like, however, especially to mention my first animal technician, the late Mr. A. S. Appleby, who helped to work out the routine of exposure and whose painstaking care made these prolonged experiments possible.

Mr. N. E. Bevan also has assisted me from the beginning in the development of dust inhalation and sampling techniques, and Mr. M. Williams had charge of the animals in the last experiment.

Mr. T. J. H. Cooke has carried out all the lung dust estimations, except for the Al_2O_3 estimations in the first experiment, which were done by Dr. T. G. Morris.

The drawings were prepared by Mr. W. H. Roberts.

I am indebted to Mr. P. D. Oldham for the statistical treatment of the results and for much valuable advice, and to Mr. S. A. Roach for much helpful criticism.

Finally, I am grateful to the former and present Directors of this Unit, Dr. C. M. Fletcher and Dr. J. C. Gilson, for providing the facilities and encouragement to carry out this work.

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APPENDIX

The Extraction of Dust from Tissues

Principle.—The tissues are dehydrated with alcohol, defatted with ether, and dissolved in hot concentrated HCl. Acid-insoluble material is then removed by centrifugation, dried, and weighed.

Technique.—The tissues are fixed by immersion in absolute alcohol overnight. Any dissection or examination required, *e.g.*, separation of lungs and hilar glands from the heart, is then carried out, and the tissues cut into slices about 2 mm. thick. These are placed in centrifuge tubes and covered with absolute alcohol, and again left overnight. The following morning the alcohol is poured off and replaced by ether, which is changed once and then left overnight. Next morning the ether is poured off, and the tubes filled with hot (50° C) concentrated HCl. As soon as the residue of the ether has evaporated, the tubes are firmly stoppered and placed in a rack in an

oven or water-bath at 60° C for two to three hours. The rack is shaken from time to time, and the process of solution observed. As soon as all visible aggregates have disappeared, the tubes are removed from the rack and centrifuged at 3000 r.p.m. for two hours. The supernatant should then be clear, but as it is a dark purple or brown colour it must be examined against a very bright light. If it is opalescent, or contains visible suspended matter, the tube should be shaken up again, and the contents divided between two tubes and reheated with more acid. The deposit is washed once in alcohol and then resuspended in a small volume of alcohol, any dust clinging to the side of the tube being carefully washed down. It can then be transferred to a suitable receptacle, dried and weighed. It has been found convenient to use "bijou" screw-capped bottles, in which the samples can be kept for future reference. Drying is accelerated if these are centrifuged, and most of the supernatant removed.

Notes.—Formalinized tissues can be used, but take longer to dissolve, as do tissues which have been fixed in alcohol for some time.

Defatting is necessary because the fat does not dissolve in the acid but forms a pellicle on centrifuging, in which a good deal of dust is trapped.

The whole process could probably be accelerated by shortening the times of immersion in the second change of alcohol and in ether, but the times given are those actually used in the experiments described.

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THE EFFECT OF THE USE OF CALCINED ALUMINA IN CHINA BISCUIT PLACING ON THE HEALTH OF THE WORKMAN

BY

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The serious morbidity and mortality from silicosis among china biscuit-ware placers and oddmen and china biscuit warehouse workers, when flint was the placing medium for the biscuit firing, have been fully recorded by Arlidge (1892), Sutherland and Bryson (1926), Middleton (1936), and Meiklejohn (1947 and 1949). So alarming was the hazard that ceramic chemists and practical potters urgently strove to discover a safe placing medium, which could be used as a substitute for flint. About 1929 (Plant, 1939) laboratory researches and practical trials proved that calcined alumina (corundum) could be used satisfactorily in the manufacture of fine china. Later, following a carefully planned survey (Industrial Pulmonary Diseases Committee, 1936) among a group of furnacemen engaged in the manufacture of alumina, Sutherland, Meiklejohn, and Price (1937) concluded that " there was no evidence of pneumoconiosis or of any other form of pulmonary disease arising from the considerable dust to which these workmen were exposed ". Assured by the practical and medical evidence, china manufacturers in increasing numbers adopted alumina as a medium for biscuit placing. Meiklejohn and Jones (1948) carried out a survey among china biscuit ware workers in North Staffordshire and reviewed the furnacemen who had been examined in the inquiry 10 years previously. They reaffirmed that alumina (corundum) as used in the pottery industry had no adverse effect on the health of workmen. Finality was reached when, under the Pottery (Health) Special Regulations, 1947, the Minister of Labour and National Service prohibited the use of powdered flint or quartz with or without the addition of other materials in the placing of ware for the biscuit fire. These regulations became effective on January 7, 1948. Between 1952 and 1954 the Mass Radiography Service at Stoke-on-Trent radiographed (35 mm. film) 248 out of approximately 280 china biscuit placers and oddmen. The results accorded with previous reports: all cases of pneumoconiosis which were detected had worked in flint for varying periods or had been exposed to other forms of siliceous dust.

Then in 1955 King, Harrison, Mohanty, and Nagelschmidt reported the results of laboratory experiments, which they had conducted on the effect of alumina, aluminium phosphate, and corundum stack fume on the lungs of rats. They concluded that certain forms of alumina, particularly hydrated alumina, can produce fibrosis of the lungs nearly as severe as can be produced by quartz. They emphasized, however, that the doses of dust used in these animal experiments vastly exceeded those used in the prophylaxis of human silicosis. Commenting on these findings Middleton (1955) wrote: " the results of the present experiments are disturbing and a reassessment of the dust exposure and control in the china branch of the pottery industry appears to be indicated."

Present Investigation

The Mass Radiography Service at Stoke-on-Trent immediately arranged to conduct an enquiry at the china factories in north Staffordshire. China manufacturers in the area were asked to provide lists of all biscuit placers and oddmen in their employment, who started work after the change-over from flint to alumina and who, in addition, had no other history of exposure to dust in any other industry or process. Forty-one firms among 43 firms cooperated: the exceptions were two small firms employing only a few workmen. Twelve firms stated that none of their workmen fulfilled the requirements of the investigation. The remaining 29 firms (Table 1) provided data of 117 men of whom 99 attended for *x*-ray examination. The response

TABLE 1

YEAR OF CHANGE-OVER FROM FLINT TO ALUMINA FOR PLACING IN 29 CHINA FACTORIES IN STOKE-ON-TRENT

Year of Change-Over	Number of Firms
1930-1934	2
1935-1939	18
1940-1944	9

(84·6%), though not ideal, may be regarded as fairly satisfactory.

One of us (E.P.) interviewed each workman and, in addition to clinical facts, recorded his employment history in detail. It emerged that employers in making returns had not restricted themselves to alumina workers but had included some men who had worked with flint or had been exposed to harmful dust in other industries and processes. This notwithstanding, all the 99 workmen, who attended, had radiographs taken on full-sized film (17 in. × 14 in.). The films of the workmen with "mixed exposure" proved to be useful in avoiding bias in the reading of the radiographs, which was made without knowledge of the employment history.

Interpretation of Films

A. Meiklejohn read the films in Glasgow on three separate occasions at intervals of several days and E. Posner read them twice at Stoke-on-Trent. Two films were rejected as technically unsatisfactory; the remaining 97 (Table 2) were reported on according to the classification of the Pneumoconiosis Research Unit, Cardiff (Fletcher, Mann, Davies, Cochrane, Gilson, and Hugh-Jones, 1949; Fletcher, 1955). Table 2 gives the numbers of these cases exposed to different dusts. Both observers were in complete agreement except in four cases. In one case they disagreed on whether or not the radiographic changes amounted to category 1, simple pneumoconiosis. In the other three—all simple pneumoconiosis—they differed by one category. These four films were submitted to A. L. Cochrane and W. E. Miall of the Pneumoconiosis Research Unit for decision.

TABLE 2

EXPOSURE TO DUST OF 97 CHINA BISCUIT PLACERS AND ODDMEN RADIOGRAPHED IN 1956

Alumina only	40
Flint and alumina	15
Ex-coal-miners	19
Ex-earthenware workers and tile workers	23
Total	97

Pneumoconiosis Present

Pneumoconiosis was diagnosed in 10 cases (Table 3). All 10 had been exposed not only to alumina dust but to other dusts known to cause pneumoconiosis. Four men had been exposed to flint dust as china biscuit placers before the change-over to alumina. In one of these (Case 9) the period of exposure to flint was very short—four years—but this is not inconsistent with category 3 simple pneumoconiosis, especially after the lapse of many years.

Pneumoconiosis Absent

Eighty-seven men showed no radiographic evidence of pneumoconiosis. Indeed a noteworthy feature was the large number of films which could unhesitatingly be read as normal. Calcified tuberculous foci, usually in the hila, were present in

TABLE 3

OCCUPATIONAL HISTORY AND RADIOLOGICAL CATEGORY OF CHINA BISCUIT PLACERS AND ODDMEN (10 CASES) WITH PNEUMOCONIOSIS

Case	Age (years)	Exposure to Alumina (years)	Exposure to Flint (years)	Coal-mining (years)	Other Exposure in Pottery Industry (years)	Occupations without Dust Risk (H.M. Forces, Labourers, etc.) (years)	Radiological Category*
1	48	9	—	10	—	15	1/-/
2	55	6	—	24	—	10	2/-/
3	67	16	18	—	—	18	2B
4	42	10	—	—	10 (Earthenware biscuit placer)	7	1/-/
5	47	16	—	—	16 (Earthenware biscuit placer)	—	1/-/
6	49	12	15	—	—	—	2B
7	55	4	—	33	—	2	2/-/
8	56	6	—	25	—	5	1/-/
9	52	16	4	—	6 (China dipper)	12	3/-/
10	58	15	20	—	—	6	2/-/

* The Pneumoconiosis Research Unit classification of the radiographic shadows in pneumoconiosis is based on the size, distribution, and profusion of the opacities throughout the lung fields. Two major classes of film are recognized: (1) Pneumoconiosis with discrete opacities, 0·5 to 5·0 millimetres in diameter; simple pneumoconiosis; (2) pneumoconiosis with coalescent or massive shadows; complicated pneumoconiosis.

In simple pneumoconiosis there are three categories of increasing abnormality denoted numerically 1, 2, and 3. There is a further miscellaneous group referred to by the letter *X*. In complicated pneumoconiosis larger shadows are superimposed on a background of simple pneumoconiosis. Four categories of increasing abnormality are identified by the capital letters A, B, C, and D. For convenience of recording a system of notation has been devised. From left to right the code in its simplest form represents category of simple pneumoconiosis/category of complicated pneumoconiosis/for example, 1/-/; 2B (Fletcher *et al.*, 1949; Fletcher, 1955).

several cases but there was not a single case of active pulmonary tuberculosis.

Supplementary Enquiries

In addition to the foregoing radiological survey several other sources of information were investigated. Dr. W. W. Jones, senior medical officer of the Pneumoconiosis Medical Panel, Stoke-on-Trent, was asked about his experience of the problem since 1944. He reported that the Panel had not observed pneumoconiosis in any china worker who had been exclusively employed in alumina. Dr. R. Lockhart, medical officer of the North British Aluminium Company, Ltd., kindly followed up the furnacemen examined in the 1936 inquiry at Kinlochleven (Sutherland *et al.*, 1937). No evidence of pneumoconiosis had been noted among these workmen and several of them had been employed in the manufacture of alumina for nearly 40 years. Confirmation of this was obtained from Dr. J. Black, senior medical officer, Pneumoconiosis Medical Panels for Scotland, who stated that no case of pneumoconiosis in alumina workers had come to the notice of the Panels.

Meanwhile in a personal communication (Jan., 1957) E. J. King wrote:

> " You may be interested to know that we have since [that is, following the article cited above—A. M.] done some work which seems to indicate that heating alumina at a high temperature to dehydrate it thoroughly greatly reduces its fibrogenicity. This work is in process of being written up. It would seem probable that alumina used in potteries is thoroughly dehydrated [1,300° C. is minimum temperature aimed at in pottery ovens for china—A. M.], and so might be expected not to be nearly as fibrogenic as the Gardner alumina (XH 1010), which we used."

H.M. Inspector of Factories at Stoke-on-Trent, in reply to an enquiry, stated that no dust counts in china biscuit placing shops had been made in recent years. Some, however, are likely to be included in the Health Survey which is in progress for the Industrial Health Advisory Committee of the Ministry of Labour and National Service.

In 1948 Meiklejohn and Jones (*loc. cit.*) recorded that the conditions of work with alumina, including intensity of dust cloud and particle size under 2 microns, were not materially different from those which had existed when flint was used; in fact the workmen then stated that alumina tended to " fly ", thereby producing a dustier atmosphere than flint.

Discussion and Summary

The substitution of alumina for flint for china biscuit placing in the pottery industry in Great Britain has been regarded as one of the major achievements in the prevention of silicosis. Indeed Plant (1939), a leading china manufacturer and humanitarian, described 1937 as the " annus mirabilis ". That alumina might cause pneumoconiosis or other disease was not overlooked but careful investigations seemed to give the assurance that it could reasonably be regarded as safe. Since alumina came into general use a critical watch has been maintained for danger signs. None was observed until King and others' (1955) experimental findings and Middleton's (1955) comment came as a challenge which could not be ignored. In presenting the results of our subsequent investigations we recognize that the data are neither statistically nor scientifically adequate to enable us to state categorically that alumina, as used in china manufacture, is entirely free from risk. Judged comprehensively, however, the evidence from the various sources is reassuring.

During the next few years the critical period of exposure—20 years (Table 4)—will be reached. The problem will be kept under vigilant observation.

TABLE 4

TIME WORKED WITH ALUMINA OF 87 CHINA BISCUIT PLACERS AND ODDMEN WITHOUT RADIOLOGICAL EVIDENCE OF PNEUMOCONIOSIS

Time Worked with Alumina (Years)	Number of Workmen
<5	7
5-9	37
10-14	29
>15*	14
Total	87

* Maximum period 18 years.

We wish to thank the British Pottery Manufacturers' Federation which generously supplied the basic data; all pottery manufacturers and workmen who cooperated in the survey, and the staff of the Stoke-on-Trent Mass Radiography Service who assisted enthusiastically to complete the work expeditiously.

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AIR POLLUTION IN DIESEL BUS GARAGES

BY

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Motor vehicles emit exhaust products which are potentially noxious to a degree which depends on their ultimate concentration in the ambient air. Fitton (1957) has discussed some aspects of air pollution by road transport and has compared the emission of pollutants from petrol and diesel engines; well maintained and properly operated diesel engines emit much less carbon monoxide and unburnt fuel than petrol engines. Diesel engines are, however, liable to emit black smoke; in well maintained vehicles this may be limited to a small puff on acceleration, but in others dense black clouds may be emitted, particularly at full load. Kotin, Falk, and Thomas (1955) have reported the presence of carcinogenic hydrocarbons in smoke from an inefficiently operating diesel engine. Other potentially harmful exhaust products include oxides of nitrogen and aldehydes; these are emitted in similar concentrations by both petrol and diesel engines.

Though much analytical work on the composition of motor exhausts has been published, relatively little is known about the concentrations of pollutants (other than carbon monoxide) which traffic may produce in the air men breathe; without this information it is difficult to make any reasonable assessment of possible hazards to health. The work reported in this paper is the first part of a larger attempt to fill this deficiency in our knowledge of air pollution. We have studied air pollution in diesel bus garages where there are clearly defined groups of men who are regularly exposed to relatively high concentrations of exhaust products. In some cases the same men have been employed on similar work over long periods and sickness records are available. Raffle (1957) has studied the deaths, retirements due to ill health, and transfers to alternative work due to lung cancer amongst various groups of London Transport employees. Results of pollution measurements in any garage are only applicable to the particular types of vehicle involved and to the running conditions obtaining within it, but they are of direct relevance to the health of the men employed there.

The measurements reported here were made in two London Transport garages, and form part of a larger programme of work in which individual buses are also being tested under various running conditions. An interim report on smoke in one of the garages has already been published (Commins, Waller, and Lawther, 1956). Pollution in London streets is also being measured and further work is planned to study pollution in tunnels and in garages housing petrol-engined vehicles.

London Transport's central fleet is made up of two main types of diesel bus, designated RT and RTL; for reasons of engineering maintenance they are segregated in different garages. Both have 6-cylinder engines of 9·6 litres capacity. There are also many variations in the sizes and plans of garages. In consultation with London Transport two garages with relatively poor ventilation were selected for study. The first was Merton (Fig. 1) which houses nearly 200 buses the majority of which are RTs. It is situated in a residential and manufacturing area about seven miles to the south of Charing Cross. The second was Dalston (Fig. 2) where about 120 buses, mainly RTLs, are housed. This is in a densely populated area in north-east London. Merton garage was constructed in 1913 and Dalston in 1907. Both garages are ventilated only by natural draught.

Most of the buses leave the garages in the early morning and some return for periods during the day. All finally return during the evening, when each bus is washed and re-fuelled before being parked. There are three sets of conditions which cause pollution. First, when the buses are started up from cold in the morning a lachrymatory mist is produced for short periods; the intensity and duration of this mist varies with the temperature of the engine and of the ambient air. Secondly, a few buses remain in the pits for repairs during the day and smoke is sometimes emitted when the engines are tested, but pipes are provided to carry this away. Thirdly, high pollution is produced during the run-in in the evening; drivers leave their buses with the engine

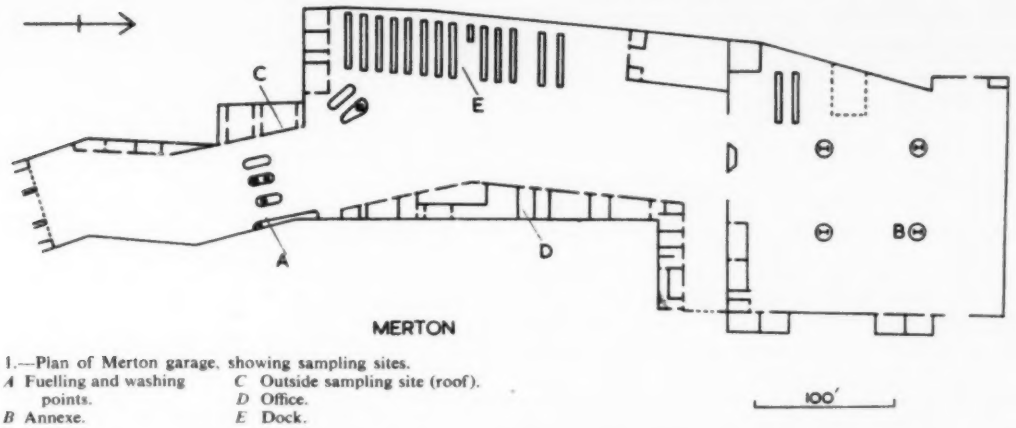

FIG. 1.—Plan of Merton garage, showing sampling sites.
A Fuelling and washing points.
B Annexe.
C Outside sampling site (roof).
D Office.
E Dock.

stopped at the mouth of the garage, and the engines are later re-started by garage staff who drive the buses up to be re-fuelled and washed. In most cases the engines are left running during these operations. The movements involve several short bursts of acceleration and a visible smoke haze is produced. Pollution is highest during this period.

Procedure

A preliminary inspection of each garage indicated that the highest pollution occurred near the fuelling and washing points. The main sampling sites were therefore established at *A* (Fig. 1) and *P* (Fig. 2). In addition to the pollution produced by the buses themselves, the air of each garage is polluted from domestic and industrial sources in the vicinity. To enable the essential comparison to be made between the air inside and outside samples were taken on the roof of each garage at sites *C* (Fig. 1) and *R* (Fig. 2). Additional samples were taken at sites *B*, *D*, and *E* (Fig. 1) and *Q*, *S*, and *T* (Fig. 2) in order to check the distribution of smoke within the garage. The staff at Merton reported that when the buses start up in the early morning the pollution is much worse in the annexe than in the rest of the garage, and for this reason the main samples at that time were taken at site *B* instead of *A* (Fig. 1). At Dalston it was less obvious which part of the garage would be the most polluted in the early morning, and in one experiment the main samples were taken at site *Q* instead of at *P* (Fig. 2).

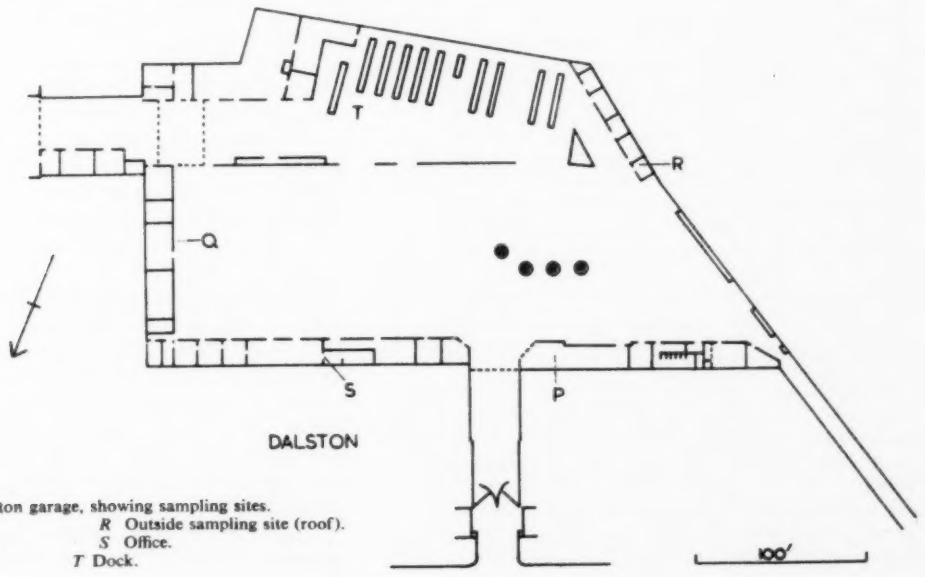

FIG. 2.—Plan of Dalston garage, showing sampling sites.
P Entrance.
Q End of garage.
R Outside sampling site (roof).
S Office.
T Dock.

Each experiment was carried out throughout one night which was divided into four periods:—

Period 1	6 p.m. to 11 p.m.	Buses re-fuelled and washed at intervals
Period 2	11 p.m. to 1 a.m.	Including main run-in; fuelling and washing in progress most of the time
Period 3	1 a.m. to 5 a.m.	Practically no vehicular activity
Period 4	5 a.m. to 7 a.m.	Including main run-out when buses leave garage at intervals

During the night of April 18/19, 1956, measurements were made at Merton garage. As the weather on this occasion was cold and misty, with high levels of pollution from local sources, the experiment was repeated on June 21/22, 1956, when pollution was lower. Two similar experiments were carried out at Dalston garage, on October 24/25, 1956, and June 19/20, 1957.

At each of the main sites samples of smoke were collected for the determination of polycyclic hydrocarbons. Measurements were made of the concentrations of nitrogen dioxide, aldehydes, carbon monoxide, and sulphur dioxide.

Methods

Samples of smoke for hydrocarbon analyses were collected on weighed glass fibre filter sheets measuring 8 in. by 10 in. overall. These were supported on a wire mesh framework and air was drawn through with a vacuum cleaner motor. The air flow through the filter was measured with a miniature float-type meter mounted in the outlet. The flow, which gradually fell as the filter became laden with smoke, was about 1 cubic metre per minute. In addition small filters were used to determine the concentration of smoke (and, at Dalston, sulphur dioxide) at five points around the garage. These were of the type specified by the Department of Scientific and Industrial Research for atmospheric pollution measurements (Parker and Richards, 1952). A continuous strip recorder (King, 1955) was used to obtain a semi-quantitative record of smoke concentration over long periods; it was started at the beginning of each experiment and was left running for one week (Dalston) and two weeks (Merton) to check day-to-day variations.

Each glass fibre filter was weighed and extracted with cyclohexane in a Soxhlet apparatus for three hours, and the yellow solution so obtained was reduced to small volume and transferred to a column of alumina. The hydrocarbons were separated by elution with cyclohexane and were determined spectrophotometrically (Commins, to be published).

The two main samplers which were used to collect smoke for hydrocarbon analyses were run side by side on a separate occasion and the concentration determined from each to ensure that they were giving comparable results. These samples were combined and used to provide material for repeated determinations of 3 : 4-benzpyrene and some other hydrocarbons. The cyclohexane extract was divided into four parts and the results of repeated analyses are given in Table 1. This experiment gave only a rough estimate of the standard deviation, but it enables some assessment to be made of the significance of differences in the main experiment. The coefficients of variation are of the same order as those found in repeated determinations on general atmospheric smoke (Commins, to be published).

TABLE 1

REPEATED DETERMINATIONS OF POLYCYCLIC HYDROCARBONS IN A SAMPLE OF SMOKE FROM MERTON GARAGE

Hydrocarbon	Hydrocarbons (μg./g. smoke)				Coefficient of Variation (%)
Pyrene	69·8	60·2	66·9	69·5	7
1 : 2-benzpyrene	36·4	33·6	31·9	31·4	7
3 : 4-benzpyrene	28·3	31·4	27·6	32·4	8
1 : 12-benzperylene	22·8	23·0	29·5	22·8	14

Nitrogen dioxide was determined colorimetrically by the method described by Saltzman (1954). Aldehydes were absorbed in sodium bisulphite solution and determined by the method of Goldman and Yagoda (1943). At Merton garage two samples of air were collected in evacuated bottles and the concentration of carbon monoxide was determined with an infra-red analyser. In addition, blood samples were taken from two subjects before and after exposure to pollution within the garage. The carbon monoxide in these samples was determined by the method of Lawther and Apthorp (1955).

Results

Smoke and Hydrocarbons.—The amounts of smoke and hydrocarbons per 100 cubic metres of air sampled inside and outside each garage are shown in Tables 2 to 5.

Except where otherwise stated the figures represent single estimations. Anthracene and 1 : 2-benzanthracene were detected but, as their determination was interfered with by some other compounds, results are not quoted. Phenanthrene, chrysene, coronene, and anthanthrene were also found in some samples. During periods 1, 2, and 4 on each occasion buses were moving in the garage, and the concentration of smoke was much higher inside than out. In general the differences in the concentrations of hydrocarbons inside and outside each garage were less marked.

Table 2 gives the results of the first experiment at Merton and shows that the concentrations of 1 : 2-benzpyrene, 3 : 4-benzpyrene, and 1 : 12-benzperylene were virtually the same inside and outside the garage during each of the four periods. Pyrene and fluoranthene concentrations were at times somewhat higher in the garage than outside. Since the concentration of smoke was higher inside the garage than outside, it is clear that the smoke produced by the buses contains a lower proportion of hydrocarbons than that outside.

TABLE 2

CONCENTRATIONS OF SMOKE AND HYDROCARBONS AT MERTON GARAGE ON APRIL 18-19, 1956

Period	Site	Smoke (mg./100 m.³)	Hydrocarbons (μg./100 m.³)				
			Pyrene	Fluoranthene	1:2-Benzpyrene	3:4-Benzpyrene*	1:12-Benzperylene
1	Garage	181	50	38	15	28	9
	Outside	92	51	18	14	34	14
2	Garage	304	95	62	35	46	29
	Outside	146	73	60	36	47	28
3	Garage	77	30	24	18	21	13
	Outside	66	28	27	15	24	11
4	Annexe	172	48	35	18	27	12
	Outside	55	17	14	20	20	10

* Mean of two estimations.

TABLE 3

CONCENTRATIONS OF SMOKE AND HYDROCARBONS AT MERTON GARAGE ON JUNE 21-22, 1956

Period	Site	Smoke (mg./100 m.³)	Hydrocarbons (μg./100 m.³)				
			Pyrene	Fluoranthene	1:2-Benzpyrene	3:4-Benzpyrene	1:12-Benzperylene
1	Garage	81	4·6	3·5	1·7	2·7	1·7
	Outside	24	1·3	1·1	1·1	1·5	1·1
2	Garage	144	17	10	2·5	2·6	1·8
	Outside	23	2·5	1·5	0·9	1·4	0·9
3	Garage	21	1·1	0·8	1·0	1·1	0·5
	Outside	18	1·3	1·8	1·9	1·8	0·5
4	Annexe	48	1·3	1·4	0·6	0·5	0·5
	Outside	14	1·1	1·4	0·5	0·6	0·3

TABLE 4

CONCENTRATIONS OF SMOKE AND HYDROCARBONS AT DALSTON GARAGE ON OCTOBER 24-25, 1956

Period	Site	Smoke (mg./100 m.³)	Hydrocarbons (μg./100 m.³)				
			Pyrene	Fluoranthene	1:2-Benzpyrene	3:4-Benzpyrene	1:12-Benzperylene
1	Garage	90	6·0	6·0	3·7	9·9	6·6
	Outside	64	4·6	4·3	3·4	11	5·6
2	Garage	26	1·4	1·4	1·1	2·4	1·4
	Outside	14	1·3	1·4	0·8	2·3	1·0
3	Garage	8	0·7	0·7	0·5	1·1	0·8
	Outside	7	0·4	†	0·4	0·9	0·5
4	Garage*	54	2·2	2·0	1·4	2·9	1·5
	Outside	16	0·9	1·1	1·2	2·2	1·9

* End of garage (*Q*, Fig. 2).
† Not determined.

TABLE 5

CONCENTRATIONS OF SMOKE AND HYDROCARBONS AT DALSTON GARAGE ON JUNE 19-20, 1957

Period	Site	Smoke (mg./100 m.³)	Hydrocarbons (μg./100 m.³)				
			Pyrene	Fluoranthene	1:2-Benzpyrene	3:4-Benzpyrene	1:12-Benzperylene
1	Garage	55	2·3	2·8	1·7	2·9	1·6
	Outside	26	1·0	0·8	1·2	2·7	0·7
2	Garage	27	0·4	0·7	0·3	0·9	0·3
	Outside	12	0·2	0·3	0·2	0·5	0·1
3	Garage	14	0·2	0·2	0·2	0·3	0·2
	Outside	6	0·05	0·1	0·1	0·3	0·1
4	Garage	36	0·6	1·1	0·8	2·3	1·1
	Outside	7	0·07	0·1	0·2	0·6	0·2

This first Merton experiment was carried out on a cold, still night and the concentration of smoke outside the garage was exceptionally high for the time of year. To assess more closely the effect of the buses the experiment was repeated in June when the general level of smoke was much lower. The concentrations of all hydrocarbons (Table 3) were very much lower than on the previous occasion, and were higher inside the garage than out during periods 1 and 2, indicating that the buses produced small amounts of hydrocarbons.

The experiments at Dalston garage were carried out in exactly the same way as those at Merton. Results from the first experiment on October 24/25 are shown in Table 4. The concentration of smoke was higher at the main sampling point inside the garage than outside at all times when buses were moving. As in the first Merton experiment the concentrations of 1 : 2-benzpyrene, 3 : 4-benzpyrene, and 1 : 12-benzperylene were virtually the same inside and outside the garage, and again the concentrations of pyrene and fluoranthene were higher inside. Although a reasonably clear day had been chosen for this experiment, the concentrations of smoke and hydrocarbons outside during the first period were rather high, due to the emission of smoke from a number of nearby domestic chimneys. Hence, as at Merton, it was necessary to repeat the experiment when the emission from chimneys was expected to be at a minimum. The results of this experiment (June, 1957) are shown in Table 5; in general the concentrations of hydrocarbons were higher inside the garage than outside, indicating again the emission of small amounts by the buses.

The results obtained with the small smoke filters at various points in and around Merton garage are given in Table 6.

TABLE 6

CONCENTRATION OF SMOKE (mg./100 m.³) AT MERTON GARAGE ON MAY 17, 1956

Site	Period	
	1	2
A, fuelling	195	210
B, annexe	24	14
C, outside	5	2
D, office	38	74
E, dock	16	4

These measurements, which were made on a separate occasion, covered the first two periods only. They indicate the relative concentrations of smoke in and around the garage, but the absolute values are only approximate. The site (*A*) chosen for the main samples within the garage did in fact show the highest concentration of smoke. Next in order of magnitude came the office site (*D*) past which most buses run; the office door was on the same side as the exhaust pipes. At Dalston garage small filters were run concurrently with the main samplers covering each of the four periods; they also were left for a fifth period (7 a.m. to 5 p.m.). Results from the first visit are shown in Table 7. Again the site (*P*) chosen for the main samples during the first three periods showed the highest smoke concentration.

TABLE 7

CONCENTRATION OF SMOKE (mg./100 m.³) AT DALSTON GARAGE ON OCTOBER 24-25, 1956

Site	Period				
	1	2	3	4	5
P, entrance	70	12	*	67	85
Q, end of garage	22	*	*	*	17
R, outside	52	*	*	*	43
S, office	12	*	*	*	23
T, dock	42	*	*	27	37

* Sample too small for assessment.

During the fourth period the main samples were collected at *Q*. It can also be seen from Table 7 that three of the garage sites showed lower concentrations of smoke than the outside sampling point (*R*). This suggested that an excessive amount of local pollution was being collected at the outside site. It came from nearby domestic chimneys, and this made it necessary to repeat the experiment during the summer when the amount of smoke from this source would be less. Results from the small filters on this second visit are shown in Table 8.

TABLE 8

CONCENTRATION OF SMOKE (mg./100 m.³) AT DALSTON GARAGE ON JUNE 19-20, 1957

Site	Period				
	1	2	3	4	5
P, entrance	63	46	11	61	20
Q, end of garage	24	8	3	21	19
R, outside	13	6	3	6	3
S, office	11	4	3	17	10
T, dock	29	20	4	34	20

The garage entrance (*P*) again showed the highest concentration of smoke in each period. On this occasion at none of the garage sites was there substantially less smoke than outside. During the day (period 5) the concentration in the dock was as high as that at the garage entrance. Sulphur dioxide concentrations were measured at each of the sites in the Dalston garage on the second visit and were well within the levels normally found in urban areas; there was no marked excess of sulphur dioxide within the garage, the highest concentration being 0·04 parts per million.

The continuous smoke sampler referred to earlier

was installed at Merton (site *A*, Fig. 1) at the beginning of each visit, and was left running for a period of two weeks. It was also installed at Dalston (site *P*, Fig. 2) at the beginning of the first visit there and was left running for one week. A smoke trace of greatly varying density was obtained with distinct " bursts " where buses had passed near during the run-in. The pattern of these " bursts " was similar on each week day with some variations at weekends. The " background " pollution was generally highest in the evening. The record showed that the level of smoke was much higher during the experiment at Merton on April 18/19 than on any of the succeeding 13 days, but that the general pattern was similar each day. There was little difference between successive days in June and the day chosen for the second experiment at Merton could be regarded as typical for the time of year. The record from Dalston showed that there was rather less pollution on the day of the first experiment there than on some of the subsequent days.

On the second visit to Dalston the continuous smoke filter was fitted with paper impregnated with thymol blue and was run through periods 1 to 4 only. A similar smoke trace was obtained, and the most intense " bursts " during the run-in in the evening showed a pink coloration around the smoke. This indicated the presence of small quantities of acid, probably sulphuric acid. The effect was no greater than that observed at times in ordinary urban air.

The concentrations of nitrogen dioxide found in Merton and Dalston garages are shown in Table 9. Some samples were taken continuously throughout each period and others were collected instantaneously in evacuated litre bottles. Analyses from the first Merton experiment show that the nitrogen dioxide appears to follow the concentration of smoke. The results quoted from the second visit to Merton are not necessarily representative of the average concentrations during each period, since they are based on instantaneous samples only. Continuous samples were taken during each of the two visits to Dalston and these followed the concentration of smoke in a similar manner. The maximum concentration of nitrogen dioxide found outside Dalston garage was 0·02 p.p.m. Samples taken in evacuated bottles a few feet from the end of the exhaust pipes of several buses at each garage contained up to 15 p.p.m. nitrogen dioxide.

TABLE 9

CONCENTRATION OF NITROGEN DIOXIDE IN MERTON AND DALSTON GARAGES

Period	Nitrogen Dioxide (p.p.m.)			
	Merton		Dalston	
	April 18-19, 1956	June 21-22, 1956	October 24-25 1956	June 19-20, 1957
1	1·2	0·13*	0·13	0·38
2	1·7 2·9*	2·7*	0·11 0·70*	0·16
3	0·04	†	0·01	0·06
4	0·30	1·3*	0·05	0·15

* Samples taken instantaneously.
† Samples not determined.

Table 10 shows the concentrations of aldehydes found in Merton and Dalston garages; any ketones present would be included in these figures. Results obtained during the three periods when buses were moving in the garage were considerably higher than those obtained during period 3. Two samples taken in evacuated bottles directly from the exhausts of buses at Merton garage were found to contain 20 and 50 p.p.m. of carbon monoxide. The amount of carbon monoxide in the blood of one subject (BTC) rose from 0·038 to 0·075 volumes % between 5.30 p.m. and 12.30 a.m., whilst that in the blood of another subject (REW) fell from 0·350 to 0·075 volumes % during the same period. Neither subject was a smoker.

TABLE 10

CONCENTRATION OF TOTAL ALDEHYDES IN MERTON AND DALSTON GARAGES

Period	Aldehydes (p.p.m.)		
	Merton		Dalston
	April 18-19, 1956	June 21-22, 1956	June 19-20, 1957
1	†	0·2	0·1
2	0·4	0·2	0·03
3	0·02	0·05	*
4	0·2	0·3	0·2

* Sample too small for assessment.
† Sample not determined.
Dalston October 24/25 results omitted because of doubts as to their validity.

Discussion

The results enable a comparison to be made of the pollution of the air inside and outside two garages. The differences in smoke concentration were greater at Merton, where there are more buses, than at Dalston. However, despite large differences in the total amount of smoke, the differences in 3 : 4-benzpyrene concentration were small. Tables 2 and 4 show that when there was moderate pollution outside there was virtually no difference between the benzpyrene concentrations inside and outside each garage. In Tables 3 and 5 it can be seen that the concentrations of 3 : 4-benzpyrene in the garages were at times a little higher than those outside. The concentrations of pyrene were, with two minor exceptions, consistently higher inside the garages. The results do not suggest that there is any difference in the emissions from RT and RTL buses.

There are two possible methods by which effects of the buses may be estimated: subtraction of the concentrations of pollutants in the outside air from those found in the garages will give valid answers only if certain assumptions are made regarding the mixing and diffusion of the two atmospheres under widely varying meteorological conditions; alternatively the outside pollution may be ignored on the occasions when it was low, and the whole of the pollution inside the garages attributed to the buses. The latter method, which will over-estimate the contribution of the buses, is to be preferred. It leads us to conclude that the buses might have been producing a concentration of 3 : 4-benzpyrene of up to 2·7 μg./100 m.^{3} at Merton garage on June 21/22, 1956, and up to 2·9 μg./100 m.^{3} at Dalston on June 19/20, 1957. These concentrations are barely one-tenth of those found in the outside air at Merton on April 18/19, 1956. The variations in the benzpyrene content of town air have been reported by one of us (Waller, 1952).

The form in which our results are presented in this paper tends to obscure the manner in which the investigation evolved; its history underlines its main conclusions. We went to Merton with no knowledge of the order of magnitude of the garage variables and we found that any contributions made by the buses to the hydrocarbon content of the air were so small as to be unrecognizable amid the high urban pollution. The experiment was repeated when the town pollution was low and a small effect of the buses was then revealed. We went to Dalston because it houses buses with a different type of engine, and, in view of our experience at Merton, we chose a day when outside pollution was expected to be low. In general pollution was low, but the smoke from a few nearby cottage chimneys made it again impossible to give a valid estimate of the rôle of the buses. We had to repeat the experiment when coal consumption in London was probably minimal. The difficulty experienced in finding conditions which permitted an assessment to be made of the hydrocarbon production of the buses in the garage illustrates the order of magnitude of their effect as compared with other urban sources of air pollution.

The special attention paid in this work to polycyclic hydrocarbons is due to their possible rôle in the aetiology of lung cancer. It is pertinent to quote at this point one of the conclusions from the paper by Raffle (1957) to which we have already referred:

> ". . . . all that can be said, on the basis of the small figures so far available, is that there is no excess of lung cancer among any group of London Transport staff such as would have been expected if diesel exhaust fumes were a serious contributory factor in producing an excess of lung cancer in urban dwellers."

The highest concentration of nitrogen dioxide found was 2·9 p.p.m. during the run-in at Merton on April 18/19, 1956, and this is below the threshold limit value of 5 p.p.m. for an eight-hour shift exposure adopted by the American Conference of Governmental Industrial Hygienists (1956).

Aldehydes merit special comment. Considerable eye irritation was experienced at Merton and Dalston particularly when buses were started from cold. Aldehydes were known to be present in exhaust fumes and, as acrolein is notorious for its lachrymatory properties even in extremely low concentration, it was thought that the eye irritation might have been caused by this substance. Acrolein could not be detected, however, by separating on paper sheets the 2 : 4-dinitrophenyl hydrazine derivatives of aldehydes (Buyske, Owen, Wilder, and Hobbs, 1956) which were collected from bus exhausts on another occasion, although other aldehydes and ketones could be identified readily. The quantities of aldehydes collected in the main experiments were insufficient for such detailed analysis but this work is continuing. The concentrations of aldehydes found did not approach the threshold limit value for formaldehyde (10 p.p.m.).

The low concentration of carbon monoxide in the garages deserves to be carefully noted.

We must emphasize again that the work reported here is of strictly limited application to the problem of pollution of the common air. It deals with air pollution in the confined spaces of garages where many buses operate under special conditions and where many men work. The results are not to be applied without qualification to air pollution under the different conditions obtaining in streets in the open air. It must be noted that London Transport derate their engines by 10% in order to reduce the possibility of heavy smoke emission and they also ensure, by a carefully arranged maintenance routine, that the engines are kept in excellent mechanical order. Work on wider aspects of the problem of air pollution by motor vehicles is continuing.

Summary

Air pollution in two London Transport diesel bus garages has been studied. Results of determinations of smoke, polycyclic hydrocarbons, nitrogen dioxide, aldehydes, carbon monoxide, and sulphur dioxide are given. These results are compared with analyses of the outside air.

Despite large differences in the concentrations of smoke inside and outside each garage only small differences in the amounts of 3 : 4-benzpyrene were noted.

Concentrations of nitrogen dioxide and alde-

hydes did not approach the threshold limit values for eight-hour shift exposures adopted by the American Conference of Governmental Industrial Hygienists in 1956. The carbon monoxide concentrations were negligible; there was no evidence of abnormal concentrations of sulphur dioxide.

The significance of these findings is discussed. Work on the problem of air pollution by motor vehicles is continuing.

Valuable technical assistance was given by Miss P. M. Harrison and R. J. Atkinson; we are indebted to London Transport Executive for providing facilities for this investigation; the high-volume samplers used were kindly loaned to us by the U.S. Public Health Service.

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OBSERVATIONS ON URINARY CADMIUM AND PROTEIN EXCRETION IN MEN EXPOSED TO CADMIUM OXIDE DUST AND FUME

BY

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Prolonged exposure of workmen in the alkaline accumulator industry to cadmium oxide dust led in many cases to the appearance of protein in the urine (Friberg, 1950). This observation has been confirmed in a preliminary publication (Smith, Kench, and Lane, 1955). Proteinuria has also been observed in men exposed to cadmium fume (Bonnell, 1955). There is reason to believe that this urinary protein is not a normal major serum protein constituent (Friberg, 1950; Kekwick, 1955). This paper presents further data on the incidence and degree of proteinuria in relation to cadmium exposure and excretion.

Materials and Methods

The subjects of this study were men exposed to cadmium oxide dust in an alkaline accumulator factory and to cadmium oxide fume in two foundries concerned with the manufacture of copper-cadmium alloy.

The accumulator factory employs some 500 workers of whom 120 had been exposed to cadmium now or in the past. The products of the factory are exclusively alkaline accumulators of various types. The positive and negative electrodes are manufactured separately, the former from a " positive mass " consisting of 80% by weight of nickel hydrate and 20% graphite. The " negative mass " is composed of 60% cadmium and 25% iron, both largely oxidized, with 3% kerosene as a binding agent. The process of manufacture is such that finely divided dust is liberated and is not entirely removed by the ventilation system.

Both foundries make a copper-cadmium alloy containing 0·5 to 1·0% cadmium for the manufacture of wire. A 50% cadmium master alloy is first prepared by addition of cadmium to molten copper, and the final copper-cadmium alloy is made by fusion of this master alloy in molten copper. The flux is stirred manually and yellow fumes of cadmium oxide are liberated at this stage. In each factory only a small group of men were engaged in the foundry (six in Foundry I and 20 in Foundry II) but a larger group worked near the furnaces.

Wide-necked pyrex bottles of 400 ml. capacity, previously cleaned and sterilized, were provided to collect urinary specimens from the workmen, a small crystal of thymol being placed in each bottle to minimize bacterial growth during transit to the laboratory. Urinary specimens from selected workmen offered the possibility of more detailed study. Spot specimens obtained mid-morning and throughout the shift were transported to the laboratory, with minimal delay, for quantitative evaluation of cadmium and protein. A group of 100 workmen of similar age range without known exposure to cadmium were used as controls.

Each specimen was examined for the presence of protein by the addition of trichloracetic acid, which was found to be the most sensitive of a number of precipitants employed. To 2 ml. urine, that had first been filtered until clear, 2 ml. 25% (w/v) trichloracetic acid was added. A just perceptible opalescence was recorded as a trace (±), definite opacity as positive (+), and a precipitate as strongly positive (++).

The urinary cadmium was determined by the dithizone method of Smith *et al.* (1955) and the total urinary protein by the biuret method of Hiller, McIntosh, and Van Slyke (1927), using 40 ml. urine instead of 2 ml. as in the original procedure.

The creatinine concentration of each specimen was determined by the alkaline picrate (Lloyd's reagent method of Owen, Iggo, Scandrett, and Stewart, 1954) and the specific gravity measured by weighing the urine in a calibrated 50 ml. volumetric flask corrected for temperature.

Each specimen was tested for reducing sugar using Benedict's qualitative reagent.

Results

The specific gravity and creatinine concentration were determined for each urinary specimen analysed for cadmium and protein. Typical examples from four workmen excreting various quantities of cadmium are given in Figs. 1 and 2.

Data on the incidence of proteinuria in this study

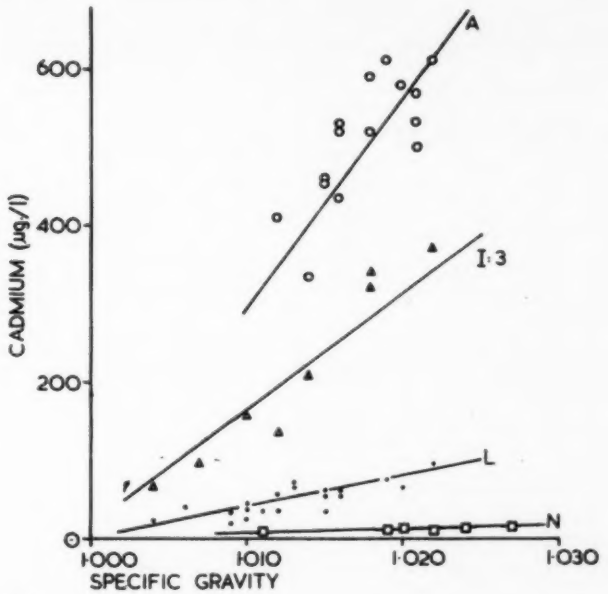

FIG. 1.—Relationship between urinary cadmium concentration and specific gravity for four workmen excreting cadmium at different rates (spot specimens).
Correlation coefficients: A, +0·77; L, +0·80; I : 3, +0·61; N, +0·64.

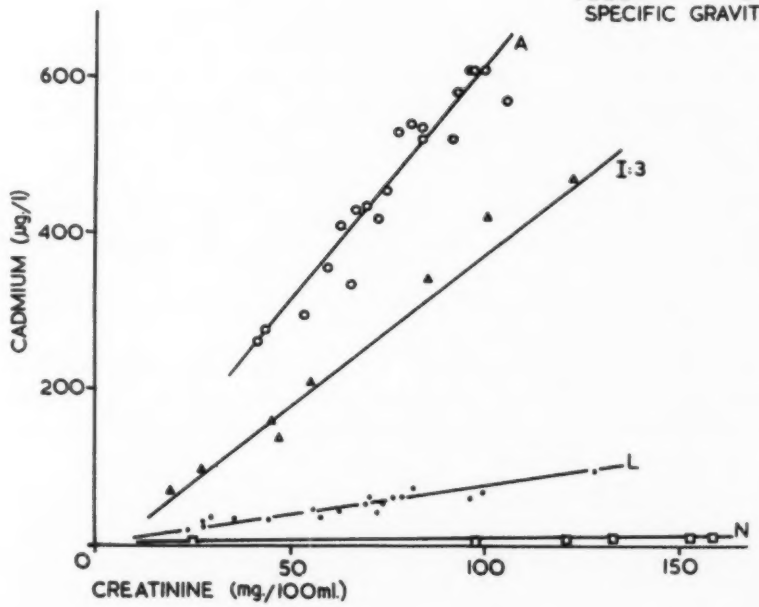

FIG. 2.—Relationship between urinary cadmium and creatinine concentration for four workmen excreting cadmium at different rates (spot specimens).
Correlation coefficients: A, +0·93; L, +0·90; I : 3, +0·99; N, +0·76.

are presented in Table 1. Proteinuria was observed in 5% of the control group of workers whereas 20% of the workers exposed to cadmium oxide dust and 60% of the workers exposed to cadmium oxide fume showed urinary protein. At this point urinary cadmium concentrations were not measured.

The results of the urinary cadmium and protein determinations are shown in Tables 2 to 10. The urinary cadmium excretion of factory and laboratory workers with no known exposure to cadmium fell within the range 0-25 µg./l. (Table 2). A group of alkaline accumulator workers not directly exposed to cadmium and with no known past exposure had urinary cadmium concentrations of 10 to 36 µg./l (Table 3). The results for a selected group of the workers in contact with various levels of cadmium in the alkaline accumulator factory are given in Table 4. The processes on which the men were

TABLE 1

INCIDENCE OF PROTEINURIA IN WORKERS EXPOSED TO CADMIUM AND IN WORKERS WITHOUT KNOWN EXPOSURE

Degree of Proteinuria	Controls	Number of Workers Exposed to		
		Cadmium Dust	Cadmium Fume I	Cadmium Fume II
+++	1	0	0	0
++	0	1	2	2
+	1	17	1	6
±	3	7	1	5
—	95	95	2	9
Total ..	100	120	6	22
Incidence of Proteinuria (%)	5	20	60	

The urinary protein was detected using 25% trichloracetic acid. Approximate quantitative equivalents of degrees of proteinuria employed are as follows:—

+++ > 5 g./l.
++ 2-5 g./l.
+ 0·25-2 g./l.
± 25-250 mg./l.
— < 25 mg./l.

engaged were graded 0-4 on the basis of the aerial cadmium contamination to which they gave rise. An exposure index was computed for each workman by summation of the products of process grading and time of exposure (in years) to give a measure of the atmospheric cadmium in the individual's working life. Tables 5 and 6 show the cadmium excretions of workers at the two foundries investigated.

Further determinations were carried out to discover the degree of variation of urinary cadmium and protein over periods of time. The results over six consecutive weeks for men exposed to cadmium oxide dust have been reported previously (Smith, *et al.*, 1955). A slight net increase in the cadmium excretion of workman *A*, who was subjected to exceptional exposure and who excreted by far the most urinary cadmium, was found during a period of one year. In other workers with lower urinary cadmium concentrations the rise was less marked but a continuous upward trend was discernible. No major fluctuations were observed over a period of two years.

The day-to-day cadmium and protein excretion of men exposed to cadmium oxide dust and fume are recorded in Tables 7 and 8 respectively. Tables 9 and 10 show the results of spot samples obtained throughout a single shift.

Discussion

The alkaline accumulator workers in this study had been exposed to cadmium oxide dust for periods varying from eight to 30 years, the severity of exposure likewise differing widely throughout the group. There was no clear relationship between their

TABLE 2

URINARY CADMIUM EXCRETION BY FACTORY AND LABORATORY WORKERS WITH NO KNOWN EXPOSURE TO CADMIUM CALCULATED FROM MORNING SPOT SAMPLES

Factory Workers						Laboratory Workers		
Subject	Cadmium (μg./l.)	Creatinine (mg./100 ml.)	Subject	Cadmium (μg./l.)	Creatinine (mg./100 ml.)	Subject	Cadmium (μg./l.)	Creatinine (mg./100 ml.)
1	6·0	78	11	14·2	82	1	4·2	92
2	2·6	26	12	4·0	52	2	5·0	116
3	21·8	78	13	18·4	102	3	6·6	104
4	5·6	46	14	14·6	72	4	3·6	80
5	6·2	62	15	16·2	90	5	4·2	66
6	6·3	76	16	7·2	60	6	14·0	92
7	20·4	96	17	1·8	26	7	5·6	70
8	18·8	80	18	22·6	84	8	9·2	112
9	19·2	108	19	10·0	94	—	—	—
10	2·0	38	20	10·0	76	—	—	—

TABLE 3

URINARY CADMIUM EXCRETION IN WORKERS NOT DIRECTLY EXPOSED TO CADMIUM BUT WORKING IN AN ALKALINE ACCUMULATOR FACTORY CALCULATED FROM MORNING SPOT SAMPLES

Specimen	Week 1			Week 2			Week 3		
	Cadmium (μg./l.)	Specific Gravity	Creatinine (mg./100 ml.)	Cadmium (μg./l.)	Specific Gravity	Creatinine (mg./100ml.)	Cadmium (μg./l.)	Specific Gravity	Creatinine (mg./100ml.)
N	16	27	160	10	19	99	12	24	154
N	10	22	122	9	11	26	12	10	134
1	20	21	93	36	23	114	—	—	—
2	34	20	86	35	18	90	—	—	—
3	31	28	124	36	20	110	—	—	—
4	31	24	108	28	18	71	—	—	—
5	28	20	—	—	—	—	—	—	—
6	10	18	84	—	—	—	—	—	—
7	33	23	104	—	—	—	—	—	—
8	15	22	92	—	—	—	—	—	—

The last two figures only of the specific gravity measured to four figures (*i.e.*, 27 = 1·027) are given.

TABLE 4
URINARY CADMIUM EXCRETION OF FACTORY WORKERS EXPOSED TO CADMIUM OXIDE DUST CALCULATED FROM MORNING SPOT SPECIMENS

Specimen	Current Exposure Rating	Exposure Time (years)	Exposure Index	Proteinuria	Week 1			Week 2		
					Cadmium (μg./l.)	Specific Gravity	Creatinine (mg./100ml.)	Cadmium (μg./l.)	Specific Gravity	Creatinine (mg./100ml.)
A	4	14	49	++	420	21	97	436	20	90
D	2	30	84	±	78	21	84	81	22	98
B	2	26	72	+	81	16	60	62	17	62
E	2	17	44	−	88	30	174	68	18	77
F	2	15	38	±	73	28	162	64	22	102
G	2	16	30	−	119	23	114	132	23	125
H	2	15	30	−	118	14	66	115	18	72
C	2	11	26	−	107	20	82	79	16	62
I	2	13	24	+	170	24	154	138	16	60
R	2	10	16	±	28	23	125	37	25	129
K	1	30	53	+	56	15	68	76	18	74
J*	1	25	43	+	53	31	126	49	25	89
L	1	25	43	+	72	13	59	98	22	124
W	1	19	32	−	64	20	101	53	19	78
P	1	30	30	−	84	23	124	48	20	80
S	1	14	24	±	46	20	96	60	23	148
T	1	10	16	±	39	22	92	41	20	87
U	1	8	8	±	41	17	76	47	20	104
V	1	8	8	±	81	15	60	59	16	48
M	0	22	66	+	32	28	160	32	19	96
Z	0	20	60	+	141	17	88	60	05	20
Z^1	0	9	27	−	163	27	—	56	06	28
O	0	14	22	−	30	21	101	20	20	90
Y	0	12	20	±	73	15	52	90	21	90
Y^1	0	8	16	±	53	18	62	45	13	46
Q	0	8	16	−	15	19	92	12	17	91

*Workman J reacted as a diabetic to the glucose tolerance test.
The last two figures only of the specific gravity measured to four figures are given.

TABLE 5
URINARY CADMIUM EXCRETION OF MEN EXPOSED TO CADMIUM OXIDE FUME CALCULATED FROM MORNING SPOT SAMPLES IN FOUNDRY I

Sample	Time of Exposure (years)	Protein	Cadmium (μg./l.)	Specific Gravity	Creatinine (mg./100 ml.)
1	8	±	410	10	51
2	14	−	40	13	58
3	32	++	425	13	36
4	8	−	121	19	80
5	37	++	47	18	93
6	20	+	190	15	55

TABLE 6*
URINARY CADMIUM EXCRETION OF MEN EXPOSED TO CADMIUM OXIDE FUME CALCULATED FROM MORNING SPOT SAMPLES IN FOUNDRY II

Specimen	Time of Exposure (years)	Protein	Cadmium (μg./l.)	Specific Gravity	Creatinine (mg./100ml.)	Specimen	Time of Exposure (years)	Protein	Cadmium (μg./l.)	Specific Gravity	Creatinine (mg./100ml.)
1	29	+(1000)	26	09	36	12	6	±	17	09	32
2	5	−	54	18	96	13	16	±	72	18	71
3	8	±	68	16	73	14	29	+(1750)	82	19	85
4	7	−	72	21	90	15	10	+(1250)	270	15	51
5	9	−	16	—	62	16	16	+(1600)	91	21	97
6	6	−	92	24	128	17	6NC	−	72	20	98
7	10NC	−	32	10	46	18	6	−	52	24	123
8	22	++(2300)	114	24	115	19	9	±	220	14	48
9	29NC	+(900)	57	13	45	20	14NC	+	46	—	57
10	7NC	−	59	14	65	21	14	−	49	—	97
11	6	±	89	20	90	—	—	—	—	—	—

N.C. not currently exposed. The concentration of urinary protein (mg./l.) is given for the samples graded + and ++.

*During the period which elapsed between the observations in Table 6 and those in Table 1, the number of men involved in Foundry II increased from 21 to 22 (one man left the job and two others joined, all protein negative). In addition the proteinuria of the men had become more severe.

urinary cadmium excretion and the grading of exposure. Likewise in the men exposed to the hazard of cadmium oxide fume in the two foundries surveyed there was no correlation between time of exposure and urinary cadmium excretion.

No significant difference in urinary excretion of cadmium was apparent between the group exposed to dust and that exposed to fume. Both groups of men exhibited a urinary cadmium excretion (10 to 610 μg./l.) which extended considerably above the

TABLE 7

URINARY PROTEIN AND CADMIUM EXCRETION OF TWO MEN, A AND L, EXPOSED TO CADMIUM OXIDE DUST CALCULATED FROM MORNING SPOT SPECIMENS OBTAINED DAILY DURING TWO WORKING WEEKS

Day of Specimen	Week 1							
	A				L			
	Urinary Protein (mg./l.)	Urinary Cadmium (μg./l.)	Creatinine (mg./100ml.)	Specific Gravity	Urinary Protein (mg./l.)	Urinary Cadmium (μg./l.)	Creatinine (mg./100ml.)	Specific Gravity
1	2,820	570	106	21	1,230	66	97	19
2	2,360	520	92	18	700	34	73	15
3	2,790	610	100	22	640	33	45	12
4	1,790	530	78	16	380	34	58	13
5	1,660	460	60	15	350	33	36	09
Day of Specimen	Week 2							
	A				L			
1	4,120	610	96	19	530	56	74	15
2	2,500	520	84	16	110	23	28	04
3	2,320	430	67	16	780	49	56	12
4	2,040	410	63	12	620	62	71	15
5	2,000	455	75	15	300	—	56	14

TABLE 8

URINARY PROTEIN AND CADMIUM EXCRETION OF TWO MEN EXPOSED TO CADMIUM OXIDE FUME CALCULATED FROM MORNING SPOT SPECIMENS OBTAINED DAILY DURING A WORKING WEEK AT FOUNDRY I

Day of Specimen	1 : 3				1 : 5			
	Urinary Protein (mg./l.)	Urinary Cadmium (μg./l.)	Creatinine (mg./100 ml.)	Specific Gravity	Urinary Protein (mg./l.)	Urinary Cadmium (μg./l.)	Creatinine (mg./100 ml.)	Specific Gravity
1	1,250	158	46	10	1,325	56	81	18
2	2,740	68	20	04	975	50	114	22
3	2,430	207	56	14	1,700	34	82	17
4	3,480	136	48	12	1,380	43	131	24
5	2,850	340	86	18	2,030	53	158	27
6	2,680	96	28	07	1,930	37	137	27

TABLE 9

URINARY PROTEIN AND CADMIUM EXCRETION OF THREE MEN EXPOSED TO CADMIUM OXIDE DUST CALCULATED FROM SPECIMENS OBTAINED THROUGHOUT SHIFT

Specimen	A				D				M			
	Urinary Protein (mg./l.)	Urinary Cadmium (μg./l.)	Creatinine (mg./ 100ml.)	Specific Gravity	Urinary Protein (mg./l.)	Urinary Cadmium (μg./l.)	Creatinine (mg./ 100/ml.)	Specific Gravity	Urinary Protein (mg./l.)	Urinary Cadmium (μg./l.)	Creatinine (mg./ 100 ml.)	Specific Gravity
1	2,850	540	81	18	100	106	110	20	980	60	100	18
2	2,650	580	93	19	60	94	80	18	860	32	34	11
3	3,200	610	97	20	30	58	56	15	380	26	20	08
4	—	—	—	—	20	54	40	13	—	—	—	—

TABLE 10

URINARY PROTEIN AND CADMIUM EXCRETION OF MEN EXPOSED TO CADMIUM OXIDE FUME CALCULATED FROM SPOT SPECIMENS OBTAINED THROUGHOUT SHIFT AT FOUNDRY I

Specimen	1 : 1				1 : 2				1 : 3			
	Urinary Protein (mg./l.)	Urinary Cadmium (μg./l.)	Creatinine (mg./100ml.)	Specific Gravity	Urinary Protein (mg./l.)	Urinary Cadmium (μg./l.)	Creatinine (mg./100ml.)	Specific Gravity	Urinary Protein (mg./l.)	Urinary Cadmium (μg./l.)	Creatinine (mg./100ml.)	Specific Gravity
1	870	590	87	14	0	40	33	07	2,820	320	101	18
2	1,210	430	67	13	0	37	33	07	3,380	370	123	22
3	850	550	70	15	0	37	39	08	—	—	—	—
4	—	—	—	—	0	39	25	05	—	—	—	—
Specimen	1 : 4				1 : 5				1 : 6			
1	0	111	86	—	775	35	67	14	1,720	210	69	15
2	0	99	56	12	570	36	66	13	1,640	175	78	16
3	0	177	133	22	1,340	33	74	15	1,020	157	58	13
4	0	142	91	19	1,170	40	95	18	595	93	33	08

normal range (0 to 25 μg./l.). The alkaline accumulator workers not exposed to cadmium, whose exposure could therefore be regarded as marginal, had urinary cadmium levels (10 to 36 μg./l.) significantly above the normal range.

The values of urinary cadmium were obtained from spot specimens and thus subject to indirect variations due to changes of water excretion throughout the day. To obviate such effects, which may give a misleading value for the cadmium excretion over short periods, it is customary to collect 24-hour specimens. Under industrial conditions such collections present considerable practical difficulties in obtaining all the urine without contamination from the workers' clothing. Spot specimens were therefore obtained from the men on arrival in the morning. Since creatinine excretion was a good measure of the glomerular filtration rate, and its clearance was unaffected by at least one heavy metal, uranium (Wills, 1949), it was hoped that variations in spot specimens could be eliminated by reference to creatinine concentration. In fact, as seen in Fig. 2, a distinct linear relationship was observed between the urinary concentrations of cadmium and creatinine over a considerable range of values. The slopes of the curves vary in accordance with the cadmium clearance rates of the four workmen illustrated. A less close correlation was observed between urinary cadmium and specific gravity (Fig. 1). It would be possible to choose an arbitrary urinary standard of creatinine concentration, say 100 mg./100 ml. urine, to which all spot specimens could be referred, the cadmium concentration being corrected according to the appropriate individual curve. The values of urinary cadmium quoted have, however, not been corrected in this way.

The incidence of proteinuria was greater in workers exposed to fume (60%) and also in those inhaling dust (20%) than in the control group. The quantity of urinary protein from cadmium workers was relatively low (0 to 4 g./l.). No correlation was discovered between urinary cadmium and protein excretion. Whereas the cadmium excretion in a urinary specimen from an individual worker was related linearly to both the specific gravity and creatinine content, the protein concentration varied independently of these quantities.

The nature of the proteinuria in this intoxication is the subject of continued study and protein from workmen *A*, *L*, I : 3, I : 5, and II : 8 is being used for this purpose.

Summary

Information is presented on the urinary cadmium excretion of men exposed to cadmium oxide dust and fume and of men not so exposed.

The incidence of proteinuria in workers exposed to cadmium oxide fume (60%) and to dust (20%) was higher than in controls (5%).

Urinary cadmium excretion in individual workmen is not subject to major fluctuation over periods varying from a few hours to two years.

For individual workmen urinary concentration of cadmium was related linearly to the specific gravity and creatinine of spot specimens, over a wide range of values.

Urinary cadmium and protein excretion appeared to vary independently.

Our thanks are due to Professor R. E. Lane for his continued interest in these studies, and to Miss I. Dingwall-Fordyce for analysing our results and for helpful discussion. We are indebted to Dr. R. S. F. Schilling, Dr. D. E. Aspin, and Dr. C. L. Potts, who kindly allowed investigation of workmen under their care, and to Mr. J. H. Stringfellow and Sister M. McConnell for their careful collection and dispatch of urinary specimens. Mr. H. V. Stevenson rendered valuable assistance throughout.

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CHEMICAL AND HISTOLOGICAL POST-MORTEM STUDIES ON A WORKMAN EXPOSED FOR MANY YEARS TO CADMIUM OXIDE FUME

BY

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Post-mortem examinations of workers who died of cadmium poisoning after exposure to cadmium oxide fume have been reported by Baader (1951), Lane and Campbell (1954), and Bonnell (1955). Friberg (1950) and Friberg and Nyström (1952) reported similar examinations of workmen subjected to cadmium oxide dust.

As part of a study of cadmium intoxication it was important to establish the distribution of absorbed cadmium in various tissues both in persons exposed to cadmium and in others not in contact with this hazard, and to discover the structural response of the tissues to cadmium deposition. One fatal case is described below.

Industrial and Medical History

The man, J. R., died on July 28, 1956, aged 46 years. From the age of 14 years he had been employed for 19 years as a kiln setter in a brick works. He then worked as an alloy section caster in a copper-cadmium foundry (Foundry II; Smith and Kench, 1957) for nine years (1942-51) and was transferred to light work involving no further exposure to cadmium in 1951, presumably on account of chest trouble.

In 1953, following influenza, he developed pneumonia and pleurisy from which he slowly recovered and eventually, after five months' absence, returned to light work. In November, 1953, this workman was one of the subjects of the survey reported by Bonnell (1955) and is referred to in that publication as B3. He was then complaining of shortness of breath and was found to have emphysema, proteinuria, and a urinary cadmium excretion of 1,240 μg. a day. He remained at work until the onset of acute bronchitis and bronchopneumonia a week before death. Necropsy was performed 48 hours after death.

Necropsy Report

The patient was of very slender build but showed no external evidence of disease. On opening the chest, both lungs were seen to be voluminous, extending over the mid-line and over the anterior surface of the pericardium. The degree of anthracosis was no more than is usual in town dwellers.

The left pleural cavity contained no excess of fluid but there were a few scattered old fibrous adhesions. On section the left lung (350 g.) showed a fairly coarse emphysema (Fig. 1) with spaces up to 1 cm. across, diffuse throughout all the lobes, extending to the pleural surfaces where, particularly at the apex, bullae were present. The largest bulla was about 3·0 × 2·0 cm. in cross section.

The right pleural cavity was almost completely obliterated by dense old adhesions between which the pleura showed some recent fibrinous exudate and the pleural cavity contained a slight excess of turbid fluid. The borders of the right lung (2,200 g.) were rounded but no gross emphysematous bullae presented at the surface. The cut surfaces of all lobes of the right lung (Fig. 2) showed a widespread coarse emphysema with cavities up to 8 mm. diameter, the largest being in the upper lobe. The lung was heavy and consolidated due to the presence of a greenish-yellow coagulated fluid in many of the cavities particularly in the middle and lower lobes. No pus could be expressed from the finer bronchial tree. There was a moderate amount of tenacious mucus in the right main bronchus: the left main bronchus was clear. There was no sign of fibrosis or tuberculosis, the hilar lymph nodes were normal, and there was no atheroma in the pulmonary arteries.

The pericardial cavity contained a slight excess of yellow fluid and the parietal pericardium adherent to the right lung was covered by a light fibrinous exudate. There were a few fibrinous flecks over the right ventricle. The heart (285 g.) showed no muscular hypertrophy and the valves were normal. There was very little atheroma in the coronary arteries and aorta. The kidneys (right, 85 g., left, 125 g.) had smooth subcapsular surfaces and the

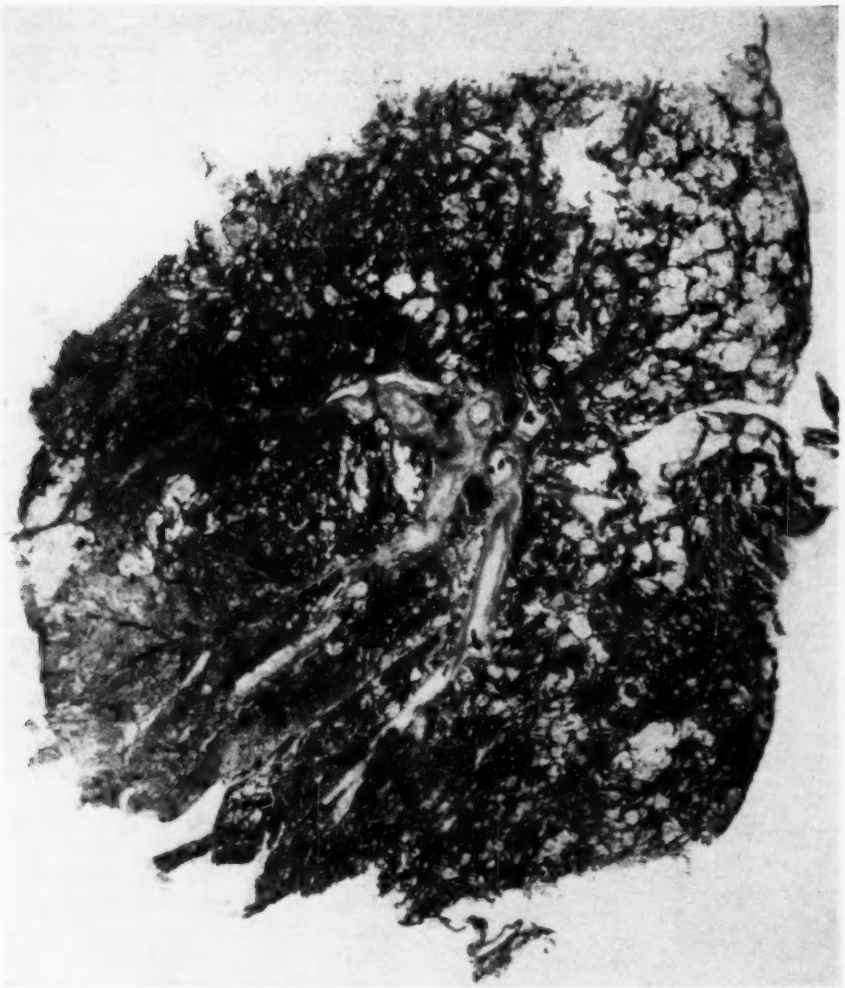

FIG. 1.—Whole section of left lung showing severe widespread emphysema.

cut surfaces showed normal cortico-medullary relationships. The pelves, ureters, bladder, prostate, seminal vesicles, and testes were normal. Other abdominal viscera, brain and meninges and the endocrine glands were normal. Fatty marrow occupied the midshaft of the femur.

Histology.—Both lungs show widespread severe emphysema. In the right lung there is a fibrino-purulent exudate in the alveolar spaces and in the lumina of the bronchi. The bronchial walls show a severe acute bronchitis in the right lung and a mild patchy acute bronchitis in the left lung. There is a notable absence of chronic inflammatory cells or of fibrosis in the bronchial walls such as would indicate a chronic bronchitis. The elastica of the residual lung tissue and the pulmonary vessels are normal.

In the kidney cortex, the glomeruli and tubules are normal. A few minor foci of atrophy and interstitial fibrosis secondary to a moderate degree of hyaline arteriolosclerosis are seen. The larger vessels are normal. There are occasional hyaline casts in collecting tubules. The renal pelvis is normal but in the submucosa of the ureters and bladder are small focal collections of macrophages and plasma cells. The seminal vesicles, prostate, and vas are normal; the testes show a little depression of spermatogenesis.

The liver is congested; the oesophagus shows a calcifying leiomyoma in its wall; no significant abnormalities are seen in the brain, heart, pancreas,

FIG. 2.—Cut surface of right lung showing severe emphysema and pneumonic consolidation.

spleen, gastro-intestinal tract, trachea, bone marrow, pituitary, thyroid, and adrenals.

Slight fatty changes in the liver and kidney are present and are compatible with terminal bacterial toxaemia. Post-mortem culture of the right lung produced a growth of *Bact. Friedlander*. Influenza viruses A, B, and C were not isolated.

Chemical Analysis

The tissue specimens were placed in pyrex bottles at necropsy and shortly afterwards dissected free from extraneous tissue. If available, quantities of approximately 5 g. fresh tissue were accurately weighed. The cadmium analysis was carried out by the dithizone procedure of Smith, Kench, and Lane (1955) which was found to be applicable to tissue, but more citrate (4 g.) was added to the acid digest before analysis as a precautionary measure. This was insufficient to prevent the formation of a heavy white precipitate of calcium phosphate on neutralization of the bone digests. One-tenth samples of the bone digests were taken and 20 g. citrate added. This greatly reduced the amount of precipitate on neutralization but it was not found possible to eliminate this effect entirely.

The results of the tissue cadmium determinations are recorded in the Table. Tissue specimens from three men of comparable age with no known exposure to cadmium were examined in the same way. Any of these tissues which exhibited abnormalities at necropsy were discarded.

Comment

As in previously reported cases of death from chronic cadmium poisoning, the salient point of attack of cadmium oxide fume was the lung parenchyma, leading ultimately to severe emphysema. Here in contrast to the case of Lane and Campbell (1954) there was no sparing of the subpleural zone; the distribution of emphysema which they described does not appear to be in any way characteristic of the poison.

Lane and Campbell stressed the absence of clinical and histological evidence of chronic bronchitis in their cases. A similar absence is noted in the necropsy case reported by Bonnell (1955). In the present case, too, there is no clinical history of a chronic cough and no histological evidence of chronic bronchitis. The presence of severe emphysema without chronic bronchitis seems to be one of the characteristic features in the earlier stages of chronic cadmium fume poisoning.

The outstanding finding is the absence of any obvious tissue damage in any organ of the body other than the lungs, despite the accumulation of cadmium.

The highest cadmium concentrations were observed in hepatic and renal tissue. Relatively, however, the least increase in cadmium deposition in J. R. as compared with controls was in the kidney. Unlike many other trace metals cadmium had no obvious predilection for bone. No histological evidence of renal damage was found to explain the proteinuria. The mild chronic inflammatory reactions in the ureters and bladder can hardly be regarded as significant and no abnormalities were found elsewhere in the urogenital tract.

TABLE
CADMIUM CONCENTRATION IN TISSUES OF A MAN EXPOSED TO CADMIUM (J. R.) AND OF THREE MEN WITHOUT KNOWN EXPOSURE

Tissue	Tissue Cadmium Concentration (μg./g. wet weight)			
	J. R. (46)	N.1 (56)	N.2 (56)	N.3 (49)
Adrenals	24	0·42	0·60	—
Artery (mesenteric)	100	—	—	—
Artery (aorta)	—	0·40	0·35	0·48
Brain	3·5	0·12	0·12	0·12
Bone marrow	4·1	0·31	0·30	0·24
Colon	20	0·29	—	0·24
Epididymis and vas	54	0·63	0·55	0·59
Gall bladder	21	0·62	0·53	0·65
Bile	24	—	0·088	0·071
Heart	11	—	0·18	0·18
Kidney cortex	150	14	18	12
Kidney medulla	130	12·5	15	8·5
Liver	160	2·0	2·8	2·1
Lung	13	0·62	0·73	0·79
Lung oedema fluid	5·0	—	—	—
Mesenteric fat	11·5	—	—	—
Skeletal muscle	7·1	0·095	0·11	0·13
Pancreas	84	—	0·35	0·61
Prostate	37	0·17	0·10	0·18
Rib cartilage	11·5	0·26	0·20	0·20
Seminal vesicles	24	—	—	—
Skin and panniculus	4·0	0·16	0·10	0·27
Spleen	55	0·35	0·29	0·36
Stomach	32	0·30	—	0·31
Testis	38	0·16	0·20	0·19
Testis capsule	94	0·30	0·32	0·34
Tongue	11	0·21	0·16	0·19
Urinary bladder	30	0·31	0·31	0·40
Bladder urine	0·34	—	—	—
Vein (mesenteric)	150	—	—	—
Vena cava	—	1·2	—	0·87
Cranium*	0·91	0·12	0·09	0·18
Femur*	1·2	0·12	0·20	0·15
Rib*	0·88	0·14	0·10	0·18

*Bone analysis unsatisfactory due to large quantities of bone mineral in acid digest.
The figures for J. R. are in most cases the arithmetic mean of duplicate analyses.

This suggests that cadmium is absorbed from the lung as a complex which, under the conditions prevalent in the tissues, is practically non-ionized. But the epithelial cells of the lung alveoli are exposed to cadmium in the form of extremely minute cadmium oxide particles. These are likely to liberate ionic cadmium which could damage and cause rupture of the alveolar walls. Repeated episodes over many years would eventually lead to the formation of emphysematous cavities.

Early removal from exposure might retard the further development of emphysema, but if at any time a chronic bronchitis were secondarily added, the emphysema would progress. In the present case, after removal from exposure, the man lived for five years with no clinical worsening of respiratory function and at necropsy no chronic bronchitis was found.

The normal biliary cadmium concentration of men aged about 50 years is of the order of 0·080μg./g. (Table). Assuming a total daily secretion of bile of 800 ml. some 64 μg. cadmium would be passed into the gut daily. The normal urinary cadmium excretion is less than 25 μg./l. If little cadmium were reabsorbed from the gut the bile would constitute a more important pathway than the urine for the elimination of body cadmium. The biliary cadmium concentration of 24 μg./g. in J. R., 300 times the normal, implies a loss of some 19 mg. cadmium by this route per day.

Summary

A further case of death from chronic poisoning by cadmium fume is described.

Severe emphysema without evidence of chronic bronchitis was observed throughout both lungs. This appears to be a characteristic feature of chronic cadmium fume poisoning in its early stages.

No significant histological changes could be detected in other organs in spite of generalized cadmium deposition.

The cadmium concentrations of all the tissues examined were considerably higher than in normal controls, the greatest quantities being in the liver and kidney with relatively little in bone.

Our thanks are due to Mr. C. Bolton, H. M. Coroner, for permission to investigate this case, and to Mr. N. Mowat for the photographs. We are indebted to Messrs. Alkaline Batteries Ltd., who supported the work by a generous grant to one of us (J. C. S.).

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AN INVESTIGATION INTO THE ACUTE RESPIRATORY REACTION TO THE INHALATION OF TAMARIND SEED PREPARATIONS

BY

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An outbreak of cough and dyspnoea among workers in textile factories was recently reported by Murray, Dingwall-Fordyce, and Lane (1957). A new sizing agent prepared from the kernel of the seed of *Tamarindus indica* had been introduced and it was thought that the condition was a reaction to a constituent of this size.

The present investigation was designed to confirm that the illnesses were due to the size and to determine, if possible, the actual constituent responsible and the nature of the reaction.

Method

Four types of dust were used in the investigation: A, a modified starch, known as K 285; B, a mixture of 75% modified starch and 25% size, consisting of ground tamarind seed, tallow, sodium silico-fluoride, and betanaphthol; C, a mixture of modified starch and the preservatives, sodium silico-fluoride and betanaphthol in the same concentration as powder B; D, a mixture of modified starch and pure tamarind flour.

A preliminary experiment was carried out in hospital with the cooperation of a velvet cutter, who had given a typical history of the condition. She was exposed first to powder A and 24 hours later to powder B. The powders were dispersed inside an oxygen tent by a small metal atomiser. Powder A (starch) produced no symptoms but a few hours after inhalation of powder B (containing tamarind) she complained of chest tightness and cough with purulent green sputum, her temperature rose to 100° F, and physiological tests showed a marked decrease in respiratory efficiency. Symptoms cleared in two or three days. Bacteriological examination of the sputum on six separate occasions showed a normal flora.

Subsequent investigations were carried out with the aid of two groups of four volunteers. The first group were women weavers employed in the rayon mill which had been most affected by the condition. Each of them had had an illness which was thought to have been due to the new size. The second group, three men and one woman, had had no known previous exposure to any form of tamarind.

The powders were administered by the machine designed by Wright (1950) in which the dust is delivered through four corrugated tubes and mouthpieces. Respiratory function was estimated from the forced expiration over 0.75 sec. using a modified Gaensler apparatus (1951). The volume was multiplied by 40 to express results in l./min. (Kennedy, 1953) as an indirect maximum volume ventilation (M.V.V.). The volunteers were given preliminary practice with this apparatus and throughout the experiment the means of the three highest readings recorded on each occasion were used for comparison. Eosinophil counts were made by the direct method.

The following routine was adopted for both groups in respect of M.V.V. measurements and for the unexposed group in respect of blood counts. Immediately before each inhalation, blood was taken for total white cell and eosinophil counts and M.V.V.s were estimated. These observations were repeated four hours later and again on the following morning. Control values for the second group were taken both during and six weeks after the end of the experiments. (This series comprised 72 blood counts and 144 M.V.V. determinations.) In order to discount errors due to diurnal variation the tests were always performed at the same time of day. Later in the experiment the afternoon eosinophil counts were omitted as it became obvious that no change occurred in so short a time. Temperatures were recorded morning and evening. (The weavers were given a thermometer and asked to take their temperature before going to bed and to bring the unshaken thermometer back the following morning.)

At the end of the experiment intradermal skin tests with increasing strengths of dilutions of the tamarind size up to 1 : 100 were carried out on the second group of volunteers.

Results

Reactions of Previously Exposed Subjects.—These subjects were not told the nature of any of the powders which they inhaled.

On the first day Powder A, modified starch, was used (Table 1). There was no subjective or objective

effect. The M.V.V.s did not alter consistently, but showed individual variations from + 12% to − 9%.

TABLE 1
MAXIMUM VOLUNTARY VENTILATION BEFORE AND FOUR HOURS AFTER INHALATION OF STARCH AND TAMARIND SIZE BY PREVIOUSLY SENSITIZED WEAVERS

Subject	M.V.V. at Start of Investigation (l./min.)	M.V.V. before Powder / M.V.V. 4 hr. after × 100		
		Powder A Starch (%)	Powder B Tamarind Size (%)	Powder A Starch (%)
1	69	91	54	87
2	94	112	60	79
3	74	96	71	97
4	105	101	75	99
Group		101*	66*	90*

*Significantly greater decrease after Powder B ($P < 0.001$).

On the second occasion Powder B, diluted tamarind size, was used. Four hours after inhalation the M.V.V.s of all four subjects showed a sharp reduction. Subjective symptoms began at about the same time with breathlessness, chest tightness, cough, and headache. All became pyrexial, the evening temperatures ranging from 98·8° F to 102° F. The following morning there was general complaint of an unpleasant and apparently characteristic taste in the mouth accompanied by dryness. In retrospect they all said that this symptom had been present during their illness in the mill. Greenish sputum produced by three of the subjects on the second day contained numerous polymorphs with a few eosinophils and on culture grew a normal bacteriological flora. The symptoms subsided rapidly although the taste and slight cough persisted for three to four days. On the fourth day a differential and total white cell count was normal in all the subjects.

After a second inhalation of Powder A, modified starch, no subjective or significant objective changes were observed.

The very considerable drop in the M.V.V. experienced by the group as a whole after inhalation of tamarind size was highly significant ($P<0.001$) when compared with the variation after starch powder.

Reactions of Subjects not Previously Exposed to Tamarind.—These subjects were first exposed to Powder B, diluted tamarind size, and a period of three weeks was allowed to elapse before the next dose. No clinical reaction followed either exposure. Inhalations of this powder were then continued twice weekly.

Subject No. 1 reacted clinically after the fourth dose. Four hours after exposure there was a marked decrease in the M.V.V., and he complained of lassitude. During the evening he had a temperature of 100·8° F. Twenty-four hours after exposure the eosinophil count had risen sharply and there was a proportionately smaller increase in the total white cells. Nine days later, having had no tamarind in the interval, he inhaled a quarter of the previous dose and reacted again in similar fashion.

The remaining subjects continued with the inhalations. After the seventh dose subject No. 2 developed headache, chest tightness and wheezing, and a slight cough. The M.V.V. dropped and he had a mild pyrexia of 98·8° F. The same type and degree of reaction occurred on two further occasions, the second of which was after an interval of 22 days and was accompanied by a rise in eosinophils.

The two remaining subjects who had not yet experienced a measurable reaction continued to inhale the powder, the dose being gradually increased to four times the original level. After the twelfth dose subject No. 3 showed a drop in the M.V.V., pyrexia of 102·5° F, eosinophilia, and leucocytosis. Subject No. 4 continued for a total of 20 exposures without developing any symptoms or signs.

Although none experienced a regular eosinophilia both the eosinophils and total white cells rose after every exposure in subjects 1 and 3 and during their first clinical reactions. These rises were highly significant ($P < 0.001$). No consistent variations occurred in the blood counts of either subject No. 2 or 4, but after his third reaction subject No. 2 had a significant rise in eosinophils (Table 2).

TABLE 2
EOSINOPHIL AND TOTAL WHITE CELL COUNTS AFTER CLINICAL REACTIONS TO DILUTED TAMARIND SIZE

Subject	Control Readings			Counts after Clinical Reactions Shown as % Ages of Control Means	
		Eosinophils	Total White Cells	Eosinophils	Total White Cells
1	Mean	122	7795	250*	140*
	σ	32	1280	200*	118φ
				(reduced dose)	
2	Mean	582	7060	105	112
	σ	99	1400	93	88
				139*	115
3	Mean	140	5580	248*	200*
	σ	39	890	144*	185*
				(reduced dose)	

* Significant increase ($P < 0.001$)
φ " " ($P < 0.01$)

The M.V.V.s showed a significant variation from the control values only at the time of clinical reactions. The maximum decreases occurred about two to five hours after the inhalation of tamarind and were nearly, if not quite, normal by the following morning (Table 3).

When it had been shown that three subjects were

TABLE 3

MAXIMUM VOLUNTARY VENTILATION DURING CLINICAL REACTIONS TO DILUTED TAMARIND SIZE

Subjects	Controls		M.V.V.s (l./min.) during Clinical Reaction * (% age of control means)
1	Mean	176	93
	σ	3·2	92 (reduced dose)
2	Mean	121	86
	σ	4·9	85
			71
3	Mean	100	76
	σ	4·0	79 (reduced dose)
			79 (Powder D)

* All these readings show a significant decrease ($P < 0.001$)

sensitive to the whole size (Powder B) they inhaled Powder C, preservatives and starch without tamarind. No reaction ensued in any of the three. The dose was repeated and again no reaction occurred.

Pure tamarind flour diluted with starch, Powder D, was inhaled by subject No. 3. There was a reaction similar to this subject's first reaction to the whole size (Table 3).

The intradermal skin tests produced no reaction in any of the subjects.

Discussion

From epidemiological evidence tamarind size was thought to be responsible for acute respiratory symptoms in a high proportion of persons processing cloth treated with it. The reactions seemed likely to be allergic in nature since a period of exposure after an interval at home resulted in a rapidly induced reaction which was much more severe than the original illness.

Further evidence that the reaction was indeed due to the tamarind size has been the demonstration that four workers who had had an illness in the mill reacted violently to the inhalation of the tamarind size and not to a starch powder. On the other hand four persons who had never been exposed to tamarind were unaffected by a few doses of the powder but after a number of doses, varying in different individuals, reacted to an amount of powder that had not previously caused any effect. These results indicate an allergic rather than a toxic basis for the reaction; the negative skin tests in no way detract from this.

It has also been shown that it was the tamarind itself and not the other constituents of the size that was responsible for the reaction. This was demonstrated by the failure of known sensitive subjects to react to the other constituents and the positive reaction produced in one individual after inhalation of the pure tamarind powder.

The inhalation of tamarind powder by the previously unexposed subjects was of limited duration, being only for 15-minute periods, usually twice a week. Although the concentration of dust they inspired may have been higher than that of the workers in the mills it would not be expected that they would develop symptoms to the same degree as the workers, who inhaled the substance for many hours every day. In fact only one of the three developed respiratory symptoms, the reaction consisting in the others of pyrexia and objective changes in respiratory function and blood count. Despite this there seems no reason to doubt that the differences in the reactions between the two groups were of degree only.

Summary

An investigation, designed to trace the association between a respiratory illness in certain textile factories and the introduction of a new sizing agent, was carried out by means of exposing volunteers to variously constituted powders.

It was shown that the ingredient of the size which was responsible for the symptoms was the ground kernel of the seed of *Tamarindus indica*.

A period of exposure proved to be necessary before the induction of a reaction and indicated an allergic rather than a toxic basis.

We are much indebted to Professor R. E. Lane who carried out the preliminary experiment and initiated the investigation. We should like to thank Mr. E. Bradbury, of The Shirley Institute, who prepared the various powders; the volunteers whose cooperation made the investigation possible; the management of Glenfield Mills, Nelson; and Mr. Shaw, of the Nelson and District Weavers Association.

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A REVIEW OF 102 CASES OF BEAT CONDITIONS OF THE KNEE

BY

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In mining, as in other occupations, entry into the groups qualifying for the higher wage rates is determined by qualification as a skilled man. For the underground worker this means production at, or close to, the coal face, and in coalfields in which the seams are comparatively thin, much of the miner's working time is spent in the performance of hard work while kneeling. With seams about 3 ft. in thickness, anything from 25% to 100% of the working shift of seven hours or so may be spent on the knees.

The common disorders of the knee which occur in men working in thin seams of coal are very well known to miners under the collective term of " beat knee ". Beat knee is a prescribed disease under the National Insurance (Industrial Injuries) Act 1946, and is defined officially as " subcutaneous cellulitis or acute bursitis arising at or about the knee ". Although the definition excludes synovial effusions into the knee joint, internal derangements of the joint, osteo-arthritis, and other morbid conditions well represented in miners, the incidence of beat knee is high. The number of cases receiving injury benefit for this condition averaged 10,305 per annum in Great Britain for the three years 1952-54.

The present paper is based on 102 cases of beat knee seen consecutively in a period of two and a half years in one area of the North Eastern (Yorkshire) Division of the National Coal Board. All were seen at colliery medical centres by the writer, and were thus judged independently of any question of their subsequent certification as cases of beat knee under the Industrial Injuries Act.

The material was obtained from seven neighbouring collieries which were well equipped and served by modern medical centres and pit-head baths. Environmental and geological conditions were comparable in the group, and the former may be summarized as follows: the working places were not deep, and were in the region of 1,000 feet below surface; ventilation and environmental working conditions were good, there being neither excessive heat nor water. The coal seams worked were generally thin, so that space was confined and work had to be done on the knees. An estimate of the thickness of the seam in the working places was obtained from 80 men. The seams were 2 ft. 6 in. or less in 35 instances, between 2 ft. 9 in. and 3 ft. 6 in. in 38, and chiefly between 3 ft. 9 in. and 4 ft. in the remaining seven.

Classification

It was found possible to classify all cases in one of three groups: (1) Inflammatory lesions, 43; (2) pressure lesions, 51; (3) other conditions, 8. As pressure and inflammatory lesions differ in aetiology, course, and treatment each will be considered separately.

Inflammatory Lesions

Inflammatory lesions usually started as infected hair follicles on the anterior or antero-lateral aspect of the knee. Many such follicular lesions run a mild course and heal with no loss of working time if situated in areas which are not subjected to occupational pressure. Miners with early follicular infections continue their work until prevented from doing so by pain or constitutional symptoms. There can be no doubt that the transmission of weight through infected foci exercises an unfavourable effect upon natural attempts at localization, with the subsequent development of follicular abscesses, commonly with a circumscribed zone of cellulitis, usually accompanied by enlarged and tender subinguinal nodes. When localization has failed altogether, a more extensive infection results. Thirteen cases were severe, 18 of moderate severity, and 12 were mild.

Follicular abscesses were present in 33 out of the 43 cases in this group. In 13 there was a single abscess; nine cases had enlarged and tender subinguinal nodes. Ten patients had single abscesses

TABLE I

RESULTS OF BACTERIOLOGICAL EXAMINATION

Organism	Coagulase Test	Antibiotic Sensitivity *in Vitro*				Cases
		Penicillin	Streptomycin	Chloramphenicol	Aureomycin	
*Staphylococcus aureus**	+	Sensitive	Sensitive	Sensitive	Sensitive	11
,, ,,	—	,,	,,	,,	,,	1
,, *albus*	+	,,	,,	,,	,,	1
,, *aureus***	+	Slightly or very slightly	,,	,,	,,	4
No growth	—	—	—	—	—	4
						21

* In one of these the staphylococcus was also sensitive to erythromycin.

** The cultures in one case were sensitive *in vitro* to erythromycin and chloramphenicol, slightly sensitive to penicillin, and sensitive to streptomycin, aureomycin, and terramycin, with a few resistant colonies.

with limited zones of cellulitis, seven of these being complicated by node enlargement and one by lymphangitis. There were three instances of extensive cellulitis arising from follicular abscesses.

Multiple follicular abscesses, often bilateral, were observed in seven men, two of whom had local cellulitis.

An acute spreading cellulitis without a follicular lesion was seen in 10 cases: six were severe and four subsiding. Constitutional symptoms usually accompanied severe cellulitis, but nodes were involved in one only.

Bacteriology.—Samples were collected by incising small follicular abscesses, or by taking material from already discharging lesions. Specimens were usually sent quickly by road to the Central Public Health Laboratory at Wakefield. Altogether 21 specimens for bacteriological investigation were obtained with the results shown in Table 1.

The clinical appearance of the spreading cellulitis when in a severe form was suggestive of a streptococcal lesion, but the only organisms isolated from these and other cases were staphylococci. A high proportion of these (13 out of 17) were fully sensitive to penicillin. Where penicillin was unsuitable or inadvisable there was a choice of alternatives.

Treatment.—Except in the milder or resolving cases treatment included the intramuscular injection of procaine penicillin without waiting for the bacteriologist's report, cessation of work with rest and elevation of the affected limb, simple instruction in quadriceps exercises, and a period of intermediate work before the patient knelt again. When considered desirable antibiotic treatment was supplemented with a short course of oral sulphonamides.

Intramuscular procaine penicillin in oil, injected into the vastus lateralis, was given in 27 cases in the series. The first 15 received an injection of 600,000 units, increased in the last 12 cases to 900,000 units. When patients were unlikely to see their private doctors for a day or so, supportive treatment was given in the form of triple sulphonamides by mouth. Thirteen patients were given such supportive treatment, each receiving 4 g. per day for two days.

The importance of early and adequate treatment of infections about the knee still needs emphasis. Further work on the sensitivity to established and newer antibiotics of staphylococci prevailing in coal-faces with thin seams might provide the basis for a systematic outline for the treatment of staphylococcal lesions. Experience in the collection of the present cases suggests that there is need for such guidance. The use of long-acting penicillin, or of penicillin in combination with another antibiotic, would doubtless receive consideration.

Shift Loss.—The time off all duty for cases in the inflammatory group averaged 14 days (10 shifts). On discharge 30 men did no alternative work which did not entail kneeling, but resumed their normal occupations. Seven performed alternative work for an average period of seven days: four men lost no time at all and two more were excluded.

Many factors besides severity of the lesion treated have a bearing on the amount of working time lost. Advice not to resume kneeling work immediately on discharge after treatment was frequently unwelcome, as alternative or standing work seriously reduces a faceworker's earning capacity.

Occupation.—The occupations of the men in the inflammatory group were: 22 fillers, five rippers, four beltmen, four borers, two deputies, and six with various other occupations.

Pressure Lesions

A total of 51 pressure lesions with effusions into bursae was seen, with the following anatomical distribution:

(i) Prepatellar bursa	30
(ii) Bursa overlying tibial tuberosity	7
(iii) (i) and (ii) combined	3
(iv) Semimembranosus bursa	6
(v) Post-operative bursae (recurrences)	4
(vi) Bursa deep to patellar tendon	1

Although pressure is a form of trauma, a distinction was made between the insidious onset of lesions which appeared to be due to prolonged occupational pressure, and those due to ordinary trauma; the latter for purposes of this classification was restricted to a clearly remembered pain-eliciting incident. Pressure lesions made themselves known by the appearance of an effusion into a bursa. In most cases patients stated that during the course of a shift they became aware of increasing discomfort in one knee while kneeling. Examination of the knee disclosed a swelling. By this time disability was considerable and kneeling was impossible.

As expected the prepatellar bursa was affected most commonly, but the appearance of effusions into the bursa overlying the tibial tuberosity was also familiar, and when present made kneeling very painful. Semimembranosus bursae when enlarged interfered much less with kneeling, but caused anxiety by their presence and a sense of discomfort on full flexion.

Clinical findings were typically a cold effusion into a bursa related to an otherwise normal knee joint. In acute cases the walls of the enlarged bursa were thin, but thickened and inelastic walls can occur in chronic cases, sometimes with crepitus resembling that of tenosynovitis. A few acute effusions were accompanied by reaction with slight local heat similar to that seen in traumatic effusions in joints, but in these as in the " cold " effusions the cause was the same, namely an aseptic inflammation of the bursa.

The estimated contents of the bursae varied from 2 or 3 ml. to much larger quantities, the most usual estimates being between 10 and 30 ml. in the three bursae most commonly affected.

In four cases the enlargement of bursae was a late post-operative recurrence with representatives of prepatellar, pretibial, and semimembranosus bursae included. In only one case was a typically dumb-bell shaped swelling of the bursa deep to the patellar tendon seen.

Apart from effusions into bursae, some occupational " thickening " is commonly observed when the knees of miners working at thin seams are examined. A careful examination of the knees of 51 rescue men (43 who were asked estimated that 64% of their working time was spent kneeling) showed that only 20 had normal knees. In 29 there was a clinical impression of a small excess of prepatellar fluid, and in two there was diffuse subcutaneous thickening. Thirty-three men were examined on the coal-face (estimated kneeling time 73% of shift), and in only 12 of these were the knees normal. In 17 there appeared to be some excess of prepatellar fluid, and in four there was diffuse thickening.

These findings indicate that small amounts of fluid in one or more prepatellar bursae, and other pressure effects, are probably common in miners working at thin seams and are compatible with full efficiency.

In considering the knee which has failed under pressure, it may be accepted that it is the appearance, accompanied by pain, of a substantial effusion into a bursa which forces the patient to seek medical advice. Remembered trauma played a negligible part in this series. The effusion is a complication of prolonged weight transmission through joint surfaces not intended for such stresses. A situation has developed in which the knee has been tested beyond the limit of adaptation, and pressure intolerance is the outcome. This explanation would apply to effusion into the semimembranosus bursa, as well as those most commonly affected, but sheds no light on the haemorrhagic nature of the effusion, an unexpected fact established regularly by aspiration.

Persistent thickening in the region of the tibial tuberosity has been seen in a number of cases receiving treatment for the knees and is alluded to by Watkins and Hunt (1954). In some cases the prominence was sufficiently obvious to suggest the desirability of radiological confirmation. Radiographs of the knee joint were taken in seven cases and thickening of the tibial cortex showed in four of these. In four radiographs there appeared to be an exaggeration, marked in one case, of the normal backward inclination of the proximal extremity of the tibia, which itself would make the tuberosity more prominent, and suggests the possibility of a plastic alteration in shape as an effect of prolonged weight bearing. This appearance is not thought to be a result of former osteochondritis.

Treatment.—Treatment consisted of cessation of all kneeling work, aspirations of the swelling if large, followed by firm bandaging, complete rest, and elevation of the limb in the more severe cases, quadriceps exercises, and, when men could be persuaded to adopt it, a period of intermediate work before resumption of kneeling. Aspiration was performed through a 17- or 16-gauge needle inserted after procaine infiltration.

Altogether bursae were aspirated in 12 cases. In five cases aspiration had to be repeated, and in one patient the same bursa was aspirated seven times. The amounts recovered at one time from the prepatellar bursa varied from 6 ml. to 63 ml. Smaller amounts were withdrawn from the bursa over the tibial tuberosity, usually only a few millilitres, but as much as 30 ml. has been obtained from this bursa.

The total number of aspirations and re-aspirations of bursae was 22, and in 17 instances in which the fluid was sent to the laboratory for bacteriological examination, no organisms were obtained on culture.

Aspiration fluid was remarkable for being visibly, usually heavily, bloodstained, in all the above cases but one; re-accumulated fluid continued to be haemorrhagic, even days after cessation of kneeling. Notwithstanding the almost constant finding of blood-stained fluid in these bursae, trauma was not an exciting cause. This finding may point to damage to the endothelial lining of the bursa as a late effect of pressure.

Aspiration appeared to be of value in treatment, and should be performed early in cases with sufficient fluid to justify it, and repeated if necessary. Aspiration should not be done, however, if the overlying skin is macerated or infected, nor in cases of effusion into the semimembranosus bursa, owing to its communication with the knee joint. The injection, after aspiration, of hyaluronidase may prove to be a useful addition to treatment, and the use in the same way of insoluble hydrocortisone may considerably hasten recovery. The intra-articular injection of hydrocortisone for sprains of the knee has been favourably reported upon by Cualacci and Bernadou (1956).

A period of work not requiring kneeling to permit full resolution of inflammatory, and especially pressure, lesions is an important step which is insufficiently appreciated and is often difficult to enforce. It is thought that many recurrences and conversions to chronic status of effusions into bursae arise from a premature return to work on the knees.

For refractory cases, especially in younger men, radical excision of the affected bursa may be the best course to advise. Thirteen examples of surgical treatment were seen in this survey. Six were successful with three men still kneeling at work 20, 10, and four years after excision of a prepatellar bursa; the other three cases were more recent but the patients had resumed kneeling two, six, and 15 months after operation. In one case operation was too recent for assessment; kneeling had been resumed four months after excision of a prepatellar bursa and was still causing pain two months later. The result of operation was disappointing in the remaining six men. Two still complained 22 years and 11 years after excision of a prepatellar bursa, and four stated that they were unable to work on their knees 27, 20, 15, and eight months after operation. The last case was prevented from kneeling by the development of an aseptic periostitis in the region of the tibial tuberosity. A post-operative recurrence of prepatellar and pretibial fluid swelling has been noted in a few cases, and one semimembranosus recurrence has been seen. Operation requires a course of rehabilitation and freedom from kneeling which may be prolonged, and it is to some extent an open question whether the protracted rest from kneeling might not have been equally effective without operation. Only the most severe cases reach the surgeon, and in some it is likely that resort has only been had to surgery when the patient's knees had lost their last vestige of tolerance to pressure, and would soon have compelled a change of occupation with or without operation.

Shift Loss.—Omitting those who could not be followed up because they failed to keep under observation or left kneeling work permanently or left the mine, and also omitting post-operative cases, there are records of 33 men. Their average loss of all work is 21 days. Twenty-three men returned to full kneeling work on discharge, a number with a small excess of fluid persisting in the affected bursa, and 10 put in a temporary period of work not requiring kneeling which averaged 24 days.

Occupation.—The occupations of the men with pressure lesions were as follows: 20 fillers, 14 rippers, five machine men, four borers, three beltmen, two shotfirers, two repairers, and one under-manager.

Other Conditions

There were eight cases classified as " other conditions ", in which the complaint was not inflammatory and not a manifestation of pressure in a bursa. Three of these were due to severe trauma causing the rapid appearance of swelling in a bursa (two in bursae overlying the tibial tuberosity and one in both the pretibial and prepatellar bursae). In two of these cases blood was aspirated. One other was a sole example of patellar tendinitis which resolved rapidly on rest and salicylates. The remaining four had tender aseptic periostitis of the tibial tuberosity, which was quite severe in one with new tibial bone laid down and calcification in the patellar tendon, and was a serious occupational disability in all cases. In another the periostitis had developed post-operatively and in the patient's own words " the disease was on the bone ". Periostitis and tendinitis do not, strictly speaking, constitute beat knee as defined in the Industrial Injuries Act.

Prevention

As long as men subject their knees to grossly unphysiological stresses, these stresses will continue to manifest themselves by the appearance of beat knee, either in its infective subcutaneous form or more deeply as a pressure lesion.

Properly designed knee pads, by cushioning weight and harmonizing irregularities in the surfaces knelt upon, must continue to be the main defence against pressure lesions. All the patients in this series wore knee pads habitually and, it may be assumed, were convinced of their value. There is, in fact, no other protection available to the almost constant kneeler. The quality of knee pads varies considerably, and certain of the heavier and better designed types are efficient. Whilst knee pads protect against pressure lesions, it is possible that under unfavourable environmental conditions they may contribute to the risk of staphylococcal lesions by excluding ventilation, macerating the skin, and acting as a trap for sharp particles of coal. It may be noted that infected abrasions were only seen in three cases in the present series, and that in only two of these could the lesion have been caused by coal particles inside the knee pads.

If the general outlook as far as the prevention of beat conditions of the knee is unpromising, particularly as regards pressure lesions, the prospects for early skilled treatment are encouraging. To be effective a recommended outline of treatment should be authoritatively codified, and publicized as necessary. These measures could be combined with a campaign amongst miners emphasizing the advantages of very early treatment in beat knee.

Summary

One hundred and two consecutive cases of beat knee are described. All occurred in coal-miners working thin seams in the North Eastern (Yorkshire) Division of the National Coal Board.

Cases were classified as inflammatory (43), pressure lesions (effusions into bursae) (51), and other conditions (eight).

Inflammatory lesions presented as folliculitis, cellulitis, or both. In 17 cases with positive cultures staphylococci were obtained, and in 13 of these the organism was sensitive to penicillin.

Pressure lesions manifested themselves by effusions into bursae, the distribution being: prepatellar 30, bursa overlying tibial tuberosity seven, the preceding two combined three, semimembranosus six, and miscellaneous affections of bursa five.

The aetiology of beat knee is discussed with particular reference to pressure lesions.

In examining the effects of pressure on the knee, it is noted that completely " normal " knees were only observed in 32 out of 84 faceworkers on thin seams who had no complaint of disability. The larger effusions into bursae which, with pain, distinguished the disabling knee, are thought to be due to an aseptic inflammation of the bursa, and appear to be the result of pressure intolerance arising from prolonged weight-bearing through joint surfaces never intended for such stresses.

In both main types of beat knee essentials in treatment include its institution at the earliest possible moment, and the prevention of kneeling both at the beginning of treatment and for some time after its conclusion, *i.e.*, on first return to work. A case can be made for the early injection of adequate amounts of intramuscular penicillin in the inflammatory forms of beat knee, and it is recommended that the commoner types of effusion into bursae should be aspirated early, and if necessary repeatedly. Despite the absence of any history of trauma, aspirated and re-aspirated bursa fluid in this series was regularly blood-stained. It is possible that improvements in treatment would result from the use of the new long-acting penicillin preparations in inflammatory cases, and the injection of hyaluronidase or hydrocortisone in pressure lesions.

Experience suggests that the preparation of standardized schemes of treatment, appropriate to inflammatory and pressure lesions, would be of value, particularly if combined with simple propaganda amongst miners emphasizing the importance of early treatment.

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VENTILATION OF IMPERMEABLE CLOTHING

THE EFFECTIVENESS OF THE AMBIENT ATMOSPHERE IN VENTILATING COVERALLS WORN IN HOT AND HUMID CONDITIONS

BY

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In the handling of highly concentrated liquids used as oxidants in guided weapons or for protection against highly toxic gases and liquids the Services require a completely impermeable coverall which can be worn for periods of up to two hours. It is well known that wearing such clothing restricts evaporative cooling and may cause collapse from heat stroke. Robinson and Belding (1948) place a limit of one hour at 75° F. and 25 minutes at 85° F. on the time of wearing such a suit. Under tropical and desert conditions the problem of cooling is particularly difficult and some form of ventilation becomes essential. Since the beginning of the century patents have been issued for devices to relieve this heat stress by circulating cooled air under clothing. None of these devices, however, is practicable for use under Service conditions in remote areas nor do they meet a requirement that the protective clothing should be self-contained, *i.e.*, it must not be attached to a remote source for cooling or dehumidifying.

It seemed, therefore, that any practical method of ventilation would necessarily be based on the use of ambient atmospheres, but no information was available about this. Although such a method cannot maintain temperature equilibrium in a wearer, except under mild conditions, it was felt desirable to ascertain the degree of alleviation which might be obtained under various conditions. To this end a study has been made of the physiological strain produced in men performing light work in a range of simulated climatic conditions while wearing impervious suits through which ambient air was pumped at controlled rates.

A practical garment would need a portable pump to supply the air, and the present data will be used in the development of a suitable pump.

Experimental

Subjects.—Nine fit young men of ages ranging from 18 to 25 years volunteered for the trials. Two were Naval ratings, six were men from these laboratories, and one was an Army officer from the Weapons Research Establishment, Woomera. Seven were used in each trial, five as subjects and the other two as controls.

Clothing.—A subject wearing the complete equipment is shown in Fig. 1.

The impervious coverall was fabricated from PVC film. All joints were welded and the material drawn in at the wrists and ankles by elastic. A slide fastener covered by a flap of the PVC material allowed the front of the garment to be opened. The neck-band was fitted with a drawstring tied to effect a seal as airtight as

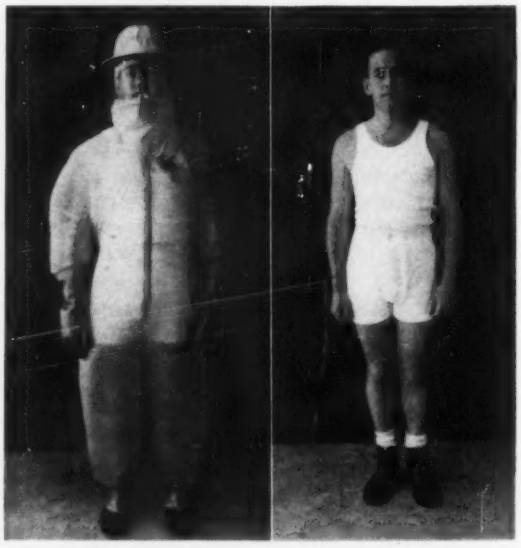


FIG. 1.—Subject and control dressed for the trials.

FIG. 2.—Subjects resting in chamber.

possible commensurate with the comfort of the wearer. The suit was worn over short cotton drawers and a cotton athletic singlet. The average free space between the coverall and the subject was approximately $1\frac{1}{2}$ ft^3.

The headgear consisted of a light-weight aluminium helmet with a clear plastic visor of 0·020 in. cellulose acetate extending round the head from the helmet brim almost to the shoulders. The visor carried a skirt of PVC film which draped over the shoulders to give a partial seal with the suit. Tubes attached to a mouth gag enabled the subjects to breathe chamber air and exhale outside the hood. Bands of cotton fabric were worn round the forehead to keep sweat out of the eyes.

Fabric-lined PVC gloves and ankle-length rubber boots with light woollen socks were worn. Gaiters of PVC film were worn over the boots and tucked up under the trouser legs to ensure that no gap existed between the trousers and the top of the boots.

A remote pump supplied ventilating air to a metal manifold in the back of the suit, from which it was distributed to six points within the suit by means of rubber tubing of $\frac{1}{4}$ in. internal diameter. Air was taken to each wrist and ankle, the small of the back, and the crown of the head. Approximately equal volumes were released at each point. The air escaped through two $\frac{1}{2}$ in. diameter holes in the shoulders of the suit.

A small thermoelectric psychrometer (see Appendix 1) was located in the left breast position for measurement of temperature and humidity within the coverall at intervals of 15 minutes throughout each trial. The suction tube and three thermocouple leads from this unit are visible in Fig. 1.

The total weight of the suit, including a small Dewar flask of ice for the thermocouple cold junction, was 4 lb. The other accessory equipment, including rubber boots and gloves, underwear, and headgear, weighed an additional 6 lb.

The subjects who acted as controls wore only cotton singlets and drawers, boots, and socks.

Chamber.—Trials were conducted in a well-insulated stainless steel chamber of 100 m^3. capacity, designed for trials with human subjects under controlled climatic conditions. During the trials wet- and dry-bulb and globe thermometer readings were taken at regular intervals. Air to ventilate the coveralls was drawn from the chamber by external pumps and passed to the subject through flexible non-kinking rubber attached to the manifold in the suit. The temperature and humidity of the pumped air were the same as those of the air in the chamber. Pumping rates of 5, 10, and 15 ft^3./min. were used.

Nature of the Exercise.—The subjects entered the chamber and the air lines and thermocouple leads were attached as soon as possible. They then rested for one hour in a sitting position (Fig. 2). Reading was permitted during this period and most subjects did so. The second hour was divided into alternate five-minute periods of light work and rest. During each work period the subjects stepped on to and down from a 9 in. step 100 times (Fig. 3), so that each person's work output in the hour was about 75,000 ft. lb. After the final rest period the subjects left the chamber.

Simulated Climatic Conditions.—The tests were carried out at temperatures ranging from 70° to 110°F. and relative humidities of 40 to 80%. In order to compare various environments it is necessary that the combined effects of the separate factors be expressed in terms of a single index. The corrected American Society of Heating and Ventilating Engineers' effective temperature scale for semi-nude persons (Bedford, 1946) was found to be the most appropriate index for this purpose under the conditions of the test.

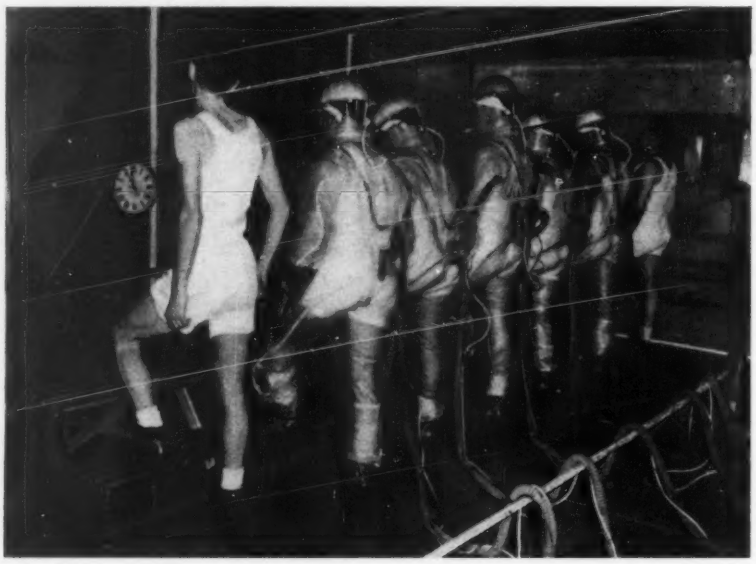


FIG. 3.—Subjects exercising in chamber.

Physiological Observations.—The following physiological data were recorded at the beginning and end of each trial.

(*a*) Rectal temperatures by means of clinical thermometer; (*b*) total sweat loss by difference in nude weight; (*c*) evaporated sweat loss by difference in clothed weight; (*d*) unevaporated sweat by increase in weight of clothing after wearing and also by difference between (*b*) and (*c*); (*e*) pulse rate was also taken at intervals during each trial; (*f*) subjects' comments on their reactions.

Pulmonary evaporative loss was not considered to be of sufficient importance to require separate recognition.

Physiological Response.—Some workers have utilized a single physiological measurement as an index; thus Craig, Garren, Frankel, and Blevins (1954) considered rectal temperature the best estimate of heat storage and consequently of heat tolerance, while McArdle, Dunham, Holling, Ladell, Scott, Thomson, and Weiner (1947) considered the sweat rate alone an adequate index of heat stress. Under conditions of extreme heat McConnell, Houghten, and Yagloglou (1924) found the pulse rate to be the best index of strain. However, Newburgh (1950), Ladell (1955), and others have shown that it can be misleading to judge a subject's response on any one factor. They quote cases of disabling heat exhaustion without a significant rise in rectal temperature.

The better known indices of strain, for example, the "index of physiological effect" of Robinson, Turrell, and Gerking (1945) or the "thermal acceptance ratio" devised by Plummer, Ionides, and Siple (1945), include skin temperature as a component. As our work employed temperatures well into the evaporative cooling zone where skin temperatures are a poor measure of heat stress, such measurements were not taken. We therefore adopted an index modified from Robinson and defined as follows:—

$$I = T + S + P$$

where I = physiological index,
T = change in rectal temperature (°F.)
S = sweat loss (lb.) and
P = final pulse rate per second, *not* per minute.

Results and Discussion

The mean values of the various observations taken during each test, together with the effective temperatures and indices of physiological strain calculated as discussed above, are shown in Table 1.

Standard deviations were not calculated as the mean values given covered only five observations. No individual result, however, varied from the mean values quoted by more than 75% of the increase in rectal temperature, 60% of the total sweat loss, or 25% of the final pulse rate.

In trials 1 to 10 the head was not ventilated, but because of some stated discomfort within the headgear, part of the ventilating air was diverted to the top of the head in later trials. Although the subjects stated that this afforded some degree of relief at the higher temperatures, there was no change in the physiological response as measured by the index.

The various indices are plotted on a logarithmic scale against effective temperature in Fig. 4. It will be noted that the sets of points corresponding to each rate of ventilation and to the response of the controls are adequately fitted with straight lines. Further, these lines (least squares fit) are almost parallel with that for the 10 ft.^{3}/min. ventilating rate equidistant from those for the 5 and 15 ft.^{3}/min. rates.

TABLE 1

EXPERIMENTAL CONDITIONS AND MEAN OBSERVATIONS ON SUBJECTS

Trial No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Atmospheric temperatures during the trial (°F.)																					
Dry bulb	72	83	93	92	92	101	102	83	82	103	92	101	110	91	89	110	82	91	81	93	90
Wet bulb	66	71	78	81	85	84	82	73	75	83	84	82	88	76	80	86	73	74	71	80	81
Effective	69	76	83	84	87	88	88	76	78	89	86	87	93	81	83	91	76	80	75	84	84
Relative humidity (%)	75	57	55	61	75	50	45	64	72	45	73	46	42	50	62	39	64	44	60	59	68
Air flow through suit (ft.³/min.)	5	5	10	10	10	10	10	5	5	10	10	15	15	5	5	15	15	15	10	15	5
Increase in rectal temperature (°F.)																					
Subject	0·8	1·0	1·5	2·3	2·3	3·1	3·2	0·4	1·3	3·1	1·8	1·9	3·9	1·6	2·1	3·0	0·3	0·7	0·4	1·3	2·3
Control	0·4	0·1	1·0	0·5	0·8	1·1	0·9	0·1	0·2	1·8	1·0	0·6	2·1	0·2	0·3	2·4	0·3	0·4	0·2	0·5	0·2
Final pulse rate per minute																					
Subject	98	114	116	120	129	134	131	99	100	138	118	122	142	113	116	126	81	94	86	104	131
Control	88	93	114	96	94	96	106	83	91	113	98	94	123	89	105	102	96	82	84	93	76
Total sweat loss (lb.)																					
Subject	0·6	1·3	2·0	2·1	2·5	3·0	3·1	1·2	1·1	3·5	2·6	2·9	3·3	2·9	2·7	2·8	0·9	1·1	1·0	2·2	1·9
Control	0·2	0·8	1·0	1·3	1·5	2·0	1·9	0·5	0·7	1·8	1·6	1·8	2·8	1·2	1·3	3·4	0·8	0·9	0·7	1·5	1·3
Physiological index																					
Subject	2·8	4·2	5·4	6·4	6·9	8·3	8·4	3·2	3·8	9·0	6·3	6·8	9·5	6·4	6·7	7·9	2·5	3·4	2·8	5·2	6·4
Control	2·2	2·2	3·8	3·3	3·8	4·6	4·5	1·8	2·2	5·5	4·2	3·9	7·4	2·7	3·1	7·4	2·6	2·6	2·3	3·4	2·8
Temperatures within suit at the beginning of the work period (°F.)																					
Dry bulb	84	89	93	94	95	98	98	90	89	97	95	98	101	92	94	100	89	93	88	93	93
Wet bulb	74	82	82	83	91	92	92	78	83	90	91	91	94	79	91	92	78	88	78	86	91
Effective	78	84	85	86	92	93	93	82	85	92	92	93	95	83	92	94	82	89	81	88	91
Effective temperature within suit at the end of the trial (°F.)	82 *a*	92 *a*	94 *a*	93 *a, b*	94 *a*	98 *a*	98 *a*	91 *a*	90 *a*	98 *a*	96	94 *b*	101 *c*	96	96	98 *b, d*	83 *b*	89 *b*	82 *b*	92 *b*	95 *b*

a—head was not ventilated.
b—only four subjects used.
c—subjects could not complete the full work and number of steps ranged from 420 to 500.
d—work limited to 500 steps.

The curves show that each additional 0·5° F. effective temperature would necessitate a 1 ft.³/min. increase in ventilation rate in order to maintain the physiological index at a steady level. Further, this figure is independent of the index within the range 2 to 10. On the other hand, at any given ventilation rate within the range 5 to 15 ft.³/min. the effect on the physiological index of increasing the effective temperature becomes more marked at higher temperatures as shown in Table 2.

TABLE 2

EFFECT OF CHANGE IN EFFECTIVE TEMPERATURE ON PHYSIOLOGICAL INDEX UNDER STANDARD WORKING CONDITIONS

Ventilating Rate (ft.³/min.)	Change in Physiological Index for Various Changes in Effective Temperature			
	70-75°F.	75-80°F.	80-85°F.	85-90°F.
5	1·2	1·8	2·4	—
10	1·0	1·4	2·2	3·2
15	—	1·2	1·8	2·4

Some difficulty was experienced in attempting to set a desirable upper limit to physiological strain as measured by the index. For example, the indices of the more copious sweaters tended to be higher than those of the other subjects. In one trial, an index of 9 was recorded, although the subject reported no undue discomfort. On the other hand, in another trial, at an index of 6, a second subject stated that conditions were barely tolerable towards the end of the two-hour period. Physical fitness was an important factor affecting endurance, for it was noted that lack of normal sleep the previous night was sometimes reflected in greater exhaustion on the part of the subject, despite the fact that the effect was not revealed in the index. Allowing for such considerations, and based on the subjects' comments and objective observation, an index of 7 was considered an acceptable upper limit under the conditions of the tests. Reference to Fig. 4 shows that, whereas a "control" would have suffered this degree of discomfort at 92·5° F. effective temperature, the subjects wearing the impervious suits would have

TABLE 3

LIMITING CLIMATIC CONDITIONS FOR A PHYSIOLOGICAL INDEX OF 7 UNDER STANDARD WORKING CONDITIONS

Dry-bulb Temperature	Maximum Wet-bulb Temperature at Various Ventilation Rates		
	5 ft.³/min.	15 ft.³/min.	Control
°F.	°F.	°F.	°F.
110	70·5	80·5	87·5
100	75	84	90·5
90	80	88	—

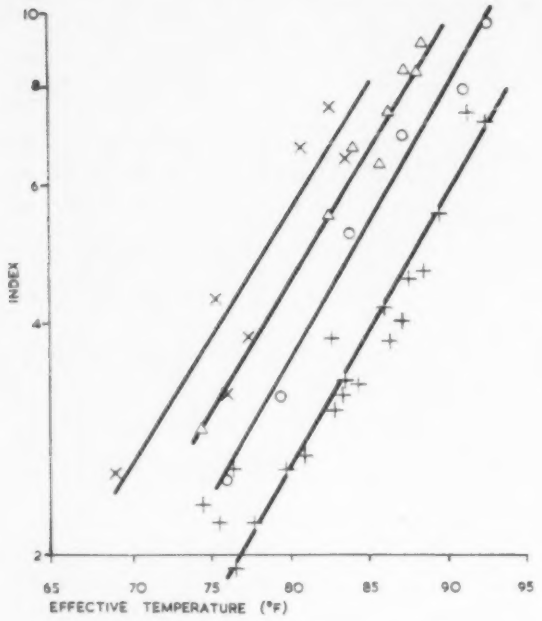


FIG. 4.—Physiological index compared with effective temperature at various ventilation rates. × 5 ft.³/min.; Δ 10 ft.³/min.; ○ 15 ft.³/min.; + Controls.

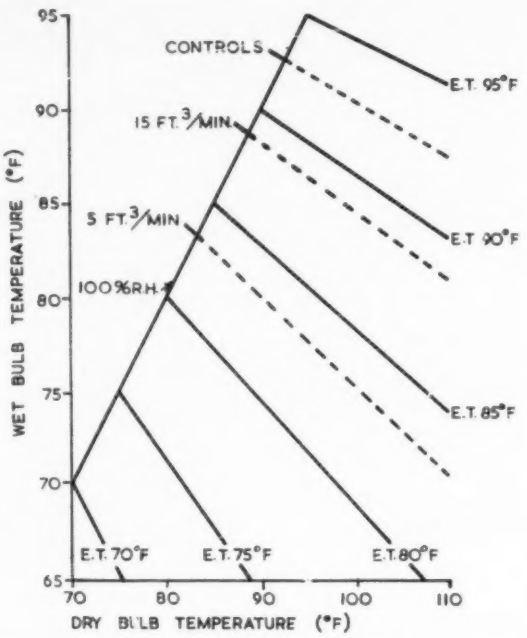


FIG. 5.—Chart showing effective temperature and limiting atmospheric conditions for a physiological index of 7.

reached a similar condition at 83·2° F. effective temperature if ventilated at 5 ft.³/min., or at 88·2° F. at 15 ft.³/min. The practical significance of these results can be seen in detail from reference to the effective temperature chart from which Table 3 has been constructed.

Linear interpolation is satisfactory within the range of the table. For practical purposes, in this range every increase of 1° F. in the wet-bulb or 2° F. in the dry-bulb temperature requires about an extra 1 ft.³/min. ventilation to maintain similar conditions of comfort. The figures are shade temperatures and take no account of solar heat load.

Fig. 5 shows effective temperatures in terms of wet- and dry-bulb temperatures. Broken lines are superimposed on the chart to correspond to a physiological index of 7 at various ventilating rates under the working conditions of the experiment. Lines corresponding to other indices can be drawn in with the aid of Fig. 4.

The supply of ventilating air was in no case sufficient to maintain thermal equilibrium nor was the degree of comfort afforded equal to that of the controls. The failure of the ventilation to maintain thermal equilibrium and the progressive discomfort suffered by the subjects was observed by psychrometric measurements of the atmosphere in the enclosed space within the coveralls, which showed a steady rise in humidity punctuated by surges at exercise periods. It rose from a few per cent. above that of the chamber atmosphere and approached saturation during the second hour of the test. In almost all cases the final relative humidity within the suit was between 95 and 100%. The difference between the rectal and enclosed space temperatures ranged from 17° F. under the mildest chamber conditions to 2·4° F. under the most severe. This difference is plotted against the physiological index in Fig. 6, which shows that a difference of approximately 6° F. corresponds to the limiting index 7, referred to above. A subject should, therefore, maintain a satisfactory thermal state and be capable of additional effort regardless of ventilation conditions provided that the difference does not become less than this figure. This criterion promises to be a very useful additional check on the response of subjects during the course of a trial.

Figs. 7, 8, and 9 show the change in rectal temperature, final pulse rate, and total sweat loss respectively, plotted against effective temperature. It will be noted that, although under certain conditions one or other of these factors appears to be a satisfactory index, *e.g.*, pulse rate at high strain, in general they are inferior to the combined index as a measure of strain over the complete range of conditions used in these experiments.

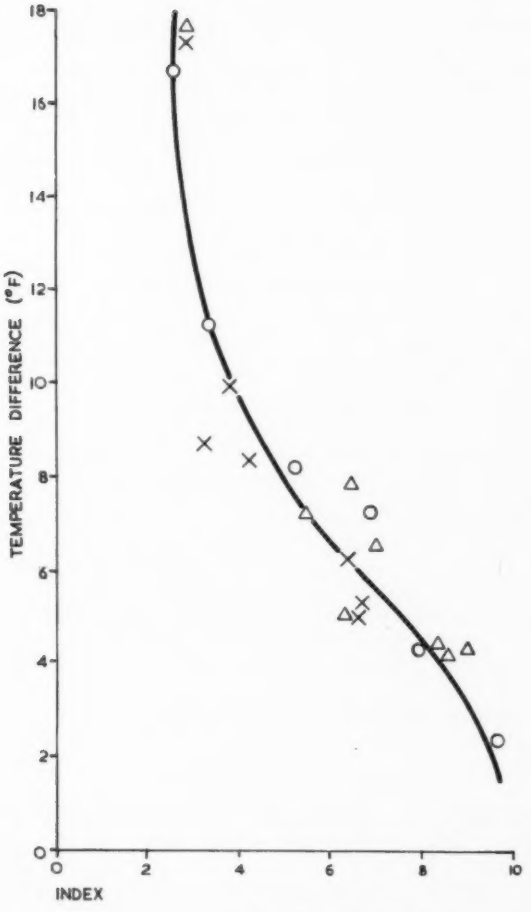


FIG. 6.—Physiological index compared with difference between rectal and suit space temperatures. × 5ft. ³/min.; Δ 10 ft.³/min.; ○ 15 ft.³/min.

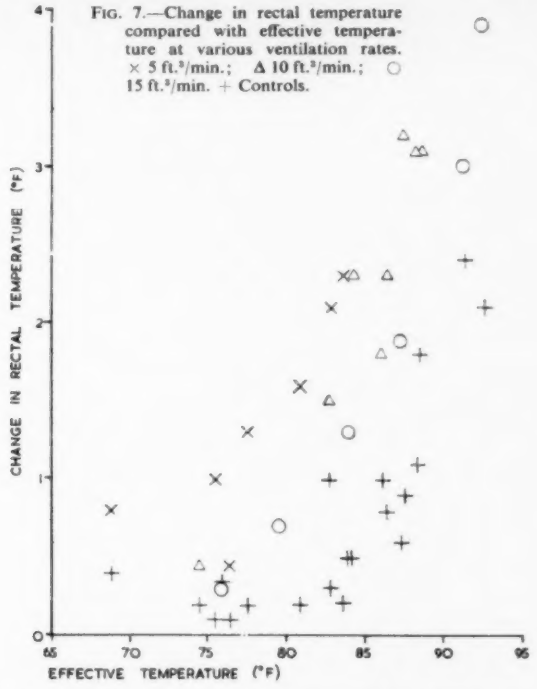


FIG. 7.—Change in rectal temperature compared with effective temperature at various ventilation rates. × 5 ft.³/min.; Δ 10 ft.³/min.; ○ 15 ft.³/min. + Controls.

FIG. 8.—Final pulse rate compared with effective temperature at various ventilation rates. × 5 ft.³/min.; Δ 10 ft.³/min.; ○ 15 ft.³/min.; + Controls.

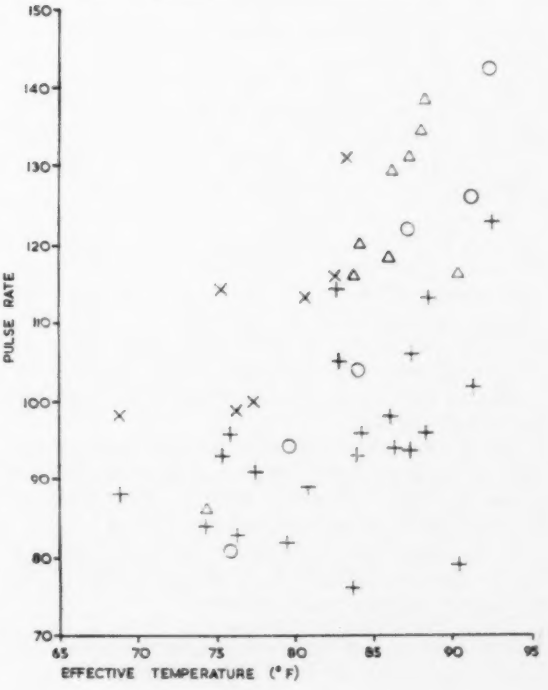
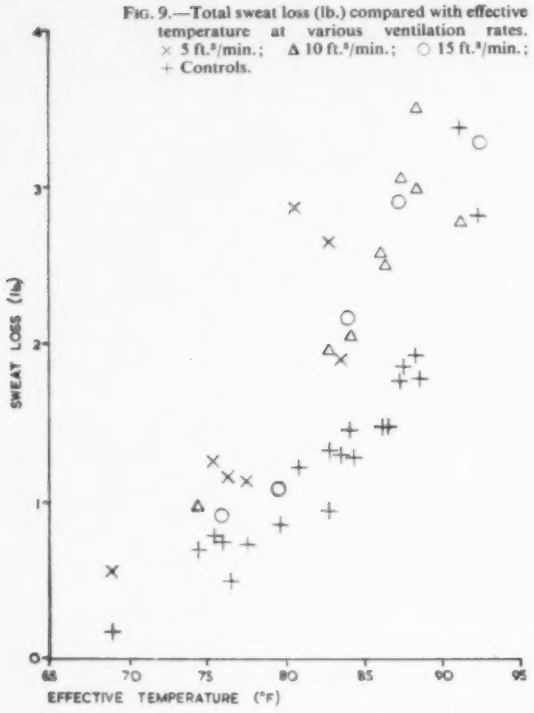


FIG. 9.—Total sweat loss (lb.) compared with effective temperature at various ventilation rates. × 5 ft.³/min.; Δ 10 ft.³/min.; ○ 15 ft.³/min.; + Controls.



Summary

Tests have been conducted using a group of healthy volunteers between 18 and 25 years of age wearing impermeable clothing and performing a standard amount of exercise under controlled conditions of temperature and humidity simulating warm, temperate, hot moist, and hot dry conditions. Lightly clothed controls were used in all tests.

The suits were ventilated with ambient air at rates of 5, 10, and 15 ft.³/min., the air being distributed to six points within the suit. No single physiological measurement was adequate under all conditions, and a composite index of strain was therefore calculated. Under the more rigorous conditions complete equilibrium of temperature could not be maintained. An index of acceptable strain was adopted.

The results relate wet-and-dry bulb temperatures with the minimum ventilating rate required to remain within the acceptable strain index. A chart showing this relationship is included as Appendix 2.

A miniature thermoelectric psychrometer to measure the wet-and-dry bulb temperatures within the suit is described in Appendix 1.

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APPENDIX 1

The Thermo-electric Psychrometer

The main body of the unit (Fig. 10) is constructed from a perspex block A. The horizontal drilling, B, which serves as the aspiration channel, extends through a small tubular section, C, at one side of the perspex block, to enable attachment of the unit to the source of suction. Two vertical drillings, D and E, connected with the aspiration channel, accommodate the leads to the wet and dry junction. The larger drilling, D, serves also as a water reservoir.

The thermocouple wires are 28 gauge constantan and 36 gauge copper. The wet junction wires are threaded through the rubber stopper, F, soldered, varnished, and wound with a single layer of loosely spun cotton. The junction is located in the aspiration channel with the ends of the thread " wick " dipping into the reservoir which is

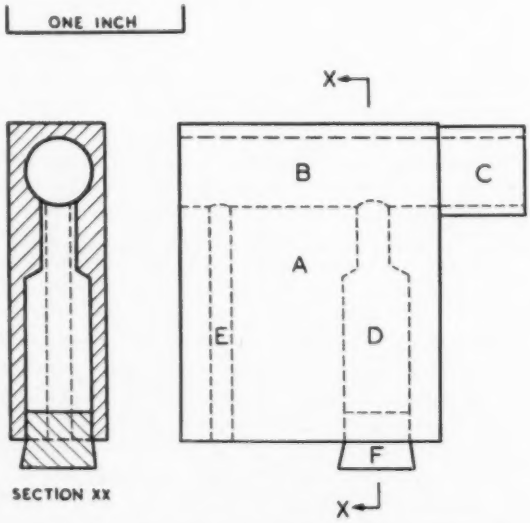

FIG. 10.—Construction of the thermo-electric psychrometer.

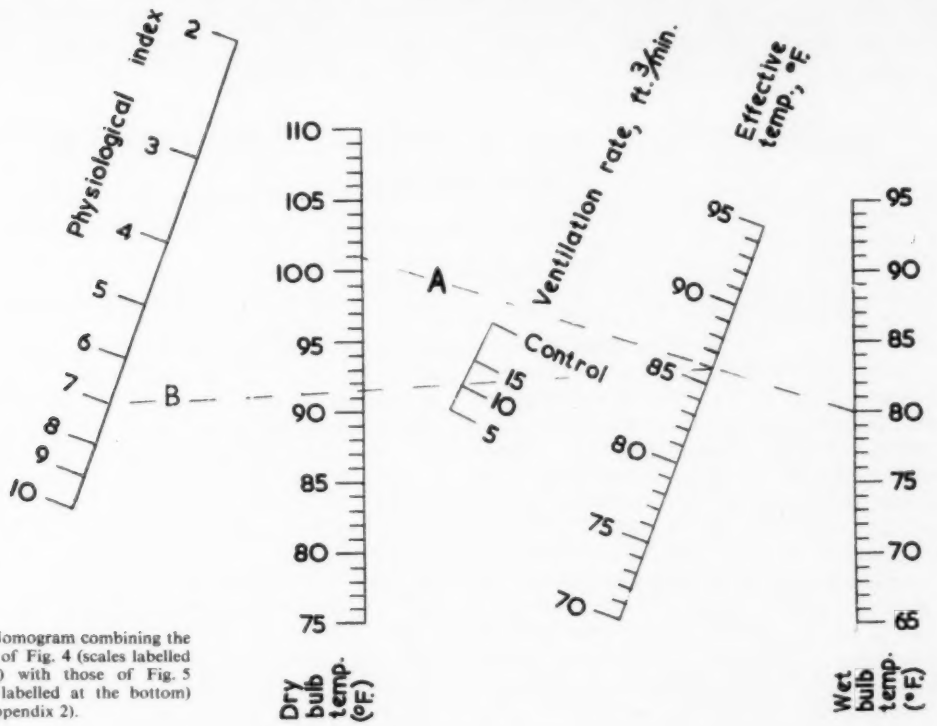

FIG. 11.—Nomogram combining the curves of Fig. 4 (scales labelled at top) with those of Fig. 5 (scales labelled at the bottom) (see Appendix 2).

filled by inserting a suitably bent pipette through the channel at C. The dry junction is soldered and threaded through the drilling E. Air is drawn through the channel at a rate of not less than 20 ml./min. An 8 in. × 1½ in. Dewar flask for the cold junction completes the unit.

APPENDIX 2

Nomogram

Fig. 11 is a nomogram which combines the curves of Fig. 4, represented by the scales labelled at the top, and those of Fig. 5 by the scales labelled at the bottom. The effective temperature scale is common to both portions of the nomogram. The broken lines A and B illustrate a typical application of the nomogram: A shows that a dry-bulb temperature of 101°F. and a wet-bulb temperature of 80°F. represent an effective temperature of 86°F., and B shows that under these conditions a ventilation rate of 10 ft³./min. is required if the physiological index is limited to 7.

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ABSENCE AND THE PHYSICAL CONDITIONS OF WORK

BY

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The early studies of the Health of Munition Workers Committee and of the Industrial Fatigue Research Board clearly demonstrated the effects of conditions of work on lost time. Loveday (1917) showed that when hours of work were long absence increased and that this was particularly marked on heavy work. Vernon (1920) compared the sickness absence of men on different occupations in the iron and steel industry and found that men employed on hot and heavy jobs experienced more sickness absence than those in other occupations. Vernon and Bedford (1928) demonstrated a relationship between atmospheric conditions in coal-mines and miners' absence. Recent research has been largely concerned with the effects of social and economic factors on absence. For instance, studies have dealt with morale (Behrend, 1951), size of undertaking (Acton Society Trust, 1953), and wage level and family responsibilities (Shepherd and Walker, 1956). However, the relative importance of these factors can only be assessed after the effects of the physical conditions on absence have been determined. It therefore seemed desirable to re-examine the relation between absence and the physical conditions of work. This paper gives the results of studies in an engineering firm and two iron and steel works where, on the whole, the conditions have improved markedly and bear little resemblance to those described in the earlier reports.

The iron and steel works were large plants employing about 4,000 and 7,000 male workers, excluding staff employees. All the processes which go to make steel products such as strip, plate, or sections, were carried out on each site. The main departments included ore preparation plants, sinter plants, coke ovens, blast furnaces, steel melting shops, and rolling mills. Most of the departments had been built or reconstructed since 1930, and many of them since the war. The working conditions were probably representative of other large undertakings in the industry. The engineering works contained a foundry and a forge in addition to three heavy engineering departments.

Sources of Data

The required information was copied from the firms' records. Such details as a man's age, length of service, and job were taken from the personnel cards; wages and income tax code number (an approximate index of family responsibilities) were extracted from the wages cards. The absences were obtained for 1952 from the absence record cards where these were maintained, and wherever possible their reliability was checked against samples of clock cards. In one of the steel firms which did not generally keep separate absence records the information was obtained from the wages cards. These were weekly records and it was not possible to determine the exact number of short-term absences although the amount of lost time was stated accurately. In one department the information had to be collected directly from the clock cards. The reasons for absence and other data, such as a list of the registered disabled persons, were recorded when they were available.

Assessment of Conditions

The multiplicity of jobs in the works made it impracticable for the investigators to attempt an objective measurement of the conditions of work. The assessment of conditions was therefore obtained from the managers and foremen who were asked to rate and rank the jobs according to the conditions which were associated with them. This was done for 296 jobs which included different and similar occupations; the latter were in different departments. The manager or foreman was given a number of cards on each of which was written the name of one of the principal jobs in his department and he arranged the jobs in order from the heaviest to the lightest. He was then given the following rating scales:—

Physical Heaviness.—1, Very heavy work; 2, heavy work; 3, medium heavy work; 4, medium; 5, medium light work; 6, light work; 7, very light work.

Continuity of Working.—1, continuous working; 2, some pauses; 3, many pauses.

Temperature.—1, hot; 2, some heat; 3, normal.

Dust.—1, very dusty; 2, fairly dusty; 3, little dust.

Fumes.—Yes or No.

The investigator read out the name of the job and the rater selected the appropriate categories on the scales. The judges were often in doubt how to rate occupations where the men were exposed to one of the conditions, particularly heat, for short periods during a shift. They were therefore asked to make the ratings refer to periods when the operators were working at the job and the assessment of the continuity of working would indicate if the men were exposed continually or intermittently to the condition. Wherever possible the ratings and rankings were obtained from more than one person and the judges were encouraged to discuss any features of the work which were unusual.

Each manager and foreman made assessments of the jobs in his own department and their reliability appeared to be satisfactory within departments. In 11 departments the coefficients of concordance (Kendall, 1948) between judges ranking jobs according to heaviness ranged from 0·55 to 0·94 with a median score of 0·87. All the scores were statistically significant at the 1% level. The ratings on the seven-point scale for the heaviness of the jobs were transformed into rank order for each department, when the number of tied cases was not too great. The rank correlation (Tau $_b$) was calculated when there were two judges and the coefficient of concordance when there were more than two judges. The coefficient in one department was significant at the 2% level and the remainder at the 1% level. These results show that there was good agreement between the judges who assessed the same jobs, although they did not measure the validity of the judgments against any objective standard. There were discrepancies in the ratings between departments; for example, crane driving in a department where the work was mainly light was rated as heavier than in a department where the work was predominantly heavy. This illustrates the effect of contrast. A light job was judged to be lighter by the supervisors when it was considered against a background of heavy jobs than when it was placed against other light jobs. Difficulties of this kind are usual when using rating techniques, but the conditions of work were observed and it seemed unlikely that these errors were sufficient to invalidate the grouping of jobs into the three categories : heavy, medium heavy, or light.

Selection of the Men

In the iron and steel works absence records were collected for all the men who were on jobs with arduous conditions and had been employed throughout the whole of 1952. A sample of one in four was selected from the men on other jobs. In the engineering works the same procedure was followed except that records were collected for all the men on the main production jobs. In this study some large groups were excluded from the samples, such as daymen employed on maintenance work as they often worked for long periods of overtime, particularly at the weekends and they were compensated by a day off during the week. It proved impossible to distinguish leave of this type from absence which was due to other reasons. General labourers were omitted from the sample, because labouring jobs were so varied as to make the rating of conditions unreliable. The registered disabled workers were also excluded.

Shift Systems

The men were employed on different shift systems with varied hours of work. The three main shift systems were:—

(1) Continuous 21-Shift Cycle.—The departments were manned continuously for 21 shifts a week throughout the year. The men worked seven shifts in succession followed by a rest period, after which they changed shifts. The sequence of change was from mornings to nights to afternoons. Over a seven-week period the hours of work averaged 48 per week in six eight-hour shifts, although some departments began to change to a 44-hour week towards the end of 1952. One department was on a discontinuous 19-shift cycle, but as the weekly hours of work and the annual planned shifts on both systems were the same, they are considered together.

(2) Discontinuous 17-Shift Cycle.—The departments were manned for 17 shifts a week from 10 p.m. on Sunday until 1 p.m. on Saturday. The men worked six morning, five afternoon, and six night shifts and changed shifts weekly in this sequence. Over a three-week period the weekly hours of work averaged 45. Two of the departments worked short time throughout part of the period and this would presumably have some effect on absence.

(3) Day Shift.—The day shifts divide into (*a*) a 44-hour four-day week, and (*b*) a 48-hour five-and-a-half day week.

Calculation of Absences

For the purpose of this study an absence has been defined as an occasion on which a man was away from work when it was planned that he would attend, and on which he lost one shift or more than one shift consecutively. Thus, if a man on the five-day week was absent on Thursday and returned to work on Friday and was then absent on the following Monday to Thursday inclusive, he would have two absences, one of one shift and one of four shifts. If he was absent on Thursday and returned to work on the following Thursday, he would have one absence of five shifts. A whole shift has been taken as the unit of attendance and absence. On the 48-hour five-and-a-half-day week the half shifts worked on Saturday mornings have been counted as whole shifts. Similarly, all half shifts lost on Saturday morning and the few others which occurred during the week have been counted as whole shifts. Absence due to late arrival or early departure has been disregarded unless it amounted to a half shift. On this basis the absence of men working on the different shift systems has been combined. The main indices of absence used in the tables are the lost time and incidence rates which take account of the shifts lost and the number of absences respectively and express them as a percentage of the possible shifts:—

$$\text{Percentage shifts lost} = \frac{\text{Shifts lost} \times 100}{\text{Possible Shifts}}$$

$$\text{Percentage incidence of absence} = \frac{\text{No. of Absences} \times 100}{\text{Possible Shifts}}$$

Shifts lost after an absence of three months have been omitted and the number of possible shifts adjusted accordingly.

The number of possible shifts in the year ranged from 246 for a man on the five-day week to 299 on the 21-shift cycle. It has been pointed out (Buzzard, 1954) that absence rates are dependent to some extent on the number of planned shifts. Whenever the data allowed, the relation between absence and conditions of work was examined for the men on the separate shift systems to ensure that any results were not due to this variation in planned shifts.

Results

Age.—Table 1 shows the absence rates of the men in the sample grouped according to age. The numbers of men in the youngest and oldest age groups were too small to provide reliable rates and their absence has been combined with the adjacent groups. Absence is lowest among the men of 35 to 44 years and is greater in the younger and older age groups. The increase among the older men is more marked for the lost time rates than the incidence rates. In the following analyses the men have been separated into those who were under and those who were over 45 years old in order to permit further division according to the conditions of work.

TABLE 1

THE ABSENCE RATES OF THE MEN BY AGE

Age	< 25	25-34	35-44	45-54	55-64	> 64	Total
No. of men	56	366	442	428	201	33	1,526
% Shifts lost	4·13		3·15	4·02	6·02		4·09
% Incidence of absence	1·81		1·46	1·53	2·10		1·67

Temperature.—Mainly furnacemen were exposed to high temperatures, and included men who worked on melting shop platforms, on the front side of blast-furnaces, and in the rolling mills, particularly on the soaking pits or other furnaces. The forge in the engineering works had puddling and reheating furnaces with attendant operations which were hot. Exposure was usually to radiant heat in an atmosphere of low humidity, and was nearly always intermittent. Vernon (1920) demonstrated that similar conditions in a more extreme form affected the incidence of sickness, especially chills. Table 2 shows the absence rates of men in both age-groups who worked on jobs where the exposure to temperature differed. There was no evidence that absence increased on hot work, in fact there was a small and irregular decrease in the absence rates with increasing exposure to heat. The trends were similar when absence on the separate shift systems was examined. The reasons for this unexpected finding are unknown. The results may reflect a high degree of selection of the men, including that afforded by medical supervision. Also, the effects of radiant heat differed between summer and winter. During the latter the heat source may have added to the comfort of working on some jobs. These questions will be considered in the discussion.

TABLE 2

ABSENCE RATES OF MEN ON WORK WITH DIFFERING EXPOSURE TO TEMPERATURE

Type of Work	Hot Work	Some Heat	No Heat
Men under 45 years old			
No. of men	204	251	409
% Shifts lost	3·10	3·61	3·89
% Incidence of absence	1·38	1·56	1·80
Men over 45 years old			
No. of men	181	207	274
% Shifts lost	4·93	3·74	5·29
% Incidence of absence	1·70	1·55	1·88

Continuity of Working.—There was wide variation in the continuity of working. In the iron and steel firms there were some occupations where the operators had little work to do for periods when the

materials were in process, for example, in the blast-furnaces and steel melting shops. In one department the men, who made up the " frontside teams " on the blast-furnaces, were required to tap the furnaces every six hours. The manager estimated that the working time involved in the quite strenuous task of tapping and clearing up afterwards averaged four hours in an eight-hour shift. In contrast, the man who controlled the passage of ingots through a cogging mill, the first of the rolling processes, was on a task which demanded continual vigilance. He was seated in a " pulpit " set above the mill and operated the controls continuously unless there was a breakdown, a shortage of ingots, or the mill was stopped for maintenance.

In the engineering firm most of the men worked continuously throughout the shift, but each man or small groups of men usually had some control over the pace of work and its distribution over the shift. This was unlike the work of the blast-furnacemen referred to above. Both the continuity and pace of work may be determined by the type of work, or by other workers, or by the individual operator, but no attempt has been made to classify the operations on this basis.

Table 3 shows the absence rates of men on jobs where the work was assessed by the managers and foremen as continuous or having some and many pauses respectively. There appears to be no consistent relationship between absence and the continuity of working, although in the over-45 age group there is an association with shifts lost, men on continuous work having more absence.

TABLE 3

ABSENCE RATES OF MEN ON JOBS WITH DIFFERING CONTINUITY OF WORKING

Type of Work	Continuous Work	Some Pauses	Many Pauses
Men under 45 years old			
No. of men	357	373	134
% Shifts lost	3·85	3·45	3·47
% Incidence of absence	1·53	1·65	1·80
Men over 45 years old			
No. of men	211	257	194
% Shifts lost	5·94	4·44	3·74
% Incidence of absence	1·98	1·54	1·69

Dust and Fumes.—When rating the jobs the managers and foremen were asked to state whether fumes were present or not, and whether the working conditions were dusty, moderately dusty, or free from dust. These conditions were less common in the engineering works than in the iron and steel firms. In the latter, men who experienced fumes worked mainly on furnaces or in the coke ovens and coke oven by-product plant. Dusty conditions were frequent in departments engaged on the initial stages of manufacture, and included exposure to particles of iron ore in the ore preparation and sinter plants and dust from coal and coke in the coke ovens. There were small groups elsewhere who experienced dust, such as the men who handled lime in a melting shop.

The number of workers exposed to one type of dust or fumes was too small for specific examination; but it has been possible to compare those on work where there were fumes and on work where there were no fumes, and within these two categories on work which was assessed as dusty or moderately dusty and that which was free from dust. The large group of workers on the 21- and 19-shift cycles in one firm was selected for analysis. The jobs of nearly all the men had been rated for fumes and dust and Table 4 compares the absence rates of those, under and over 45, who were and were not exposed to these conditions. If the extremes are considered, the absence rate of the younger men who were exposed to both dust and fumes was 2·92 and for those who were exposed to neither the rate was 3·45; for the older men the rates were 4·57 and 4·14 respectively. However, the men who were exposed to fumes alone or dust alone had higher absence rates. The results are difficult to interpret, but the evidence does not suggest that these conditions had any general effect on absence behaviour.

TABLE 4

ABSENCE RATES OF MEN EXPOSED AND NOT EXPOSED TO FUMES AND DUST

Type of Work	Fumes		No Fumes	
	Dust	No Dust	Dust	No Dust
Men under 45 years old				
No. of men	67	45	86	32
% Shifts lost	2·92	3·78	3·43	3·45
% Incidence of absence	1·25	1·57	1·38	0·97
Men over 45 years old				
No. of men	39	48	61	23
% Shifts lost	4·57	5·30	5·14	4·14
% Incidence of absence	1·11	1·90	1·66	1·42

Heaviness of Work.—The physical heaviness of each job was rated on the seven-point scale described above. This was reduced to a threefold classification, and Table 5 shows the absence rates of men on work rated as heavy, medium heavy, and light. There is an increase in the amount and incidence of absence as the work becomes heavier, and the trends are consistent in both age groups. The nature of this association will be examined later.

The next step was to consider the effects of interaction between different conditions. Although a particular condition might not influence absence from work, if two or more were present at the same time they could do so. For example, there is the expectation that continuous heavy work carried out

TABLE 5

ABSENCE RATES OF MEN ON JOBS WITH DIFFERING HEAVINESS OF WORK

Type of Work	Heavy Work	Medium Heavy	Light Work
Men under 45 years old			
No. of men	242	315	307
% Shifts lost	4·93	3·61	2·59
% Incidence of absence	2·21	1·61	1·18
Men over 45 years old			
No. of men	266	191	205
% Shifts lost	5·03	4·85	4·10
% Incidence of absence	2·08	1·77	1·21

in a hot environment would be associated with high absence rates; but owing to the small numbers of men it was only possible to examine the effects of two factors at a time. One comparison of this kind was found to show a relationship. Table 6 and Fig. 1 give the absence rates of men on jobs where the heaviness and continuity of working differed.

The results show (Fig. 1) that when the work is continuous or has some pauses in activity, absence rates decrease as the work also becomes lighter. For example, the lost time rates of the younger men on continuous work were 6·77, 3·74, and 2·49 for those on heavy, medium heavy, and light work respectively. This trend is not sustained on work with many pauses in activity. Table 6 also shows that on heavy work absence decreases as there are more pauses in activity. For example, the lost time rates of the younger men on heavy work were 6·77, 4·36, and 3·64 for those on continuous work or work with some and many pauses respectively. On medium heavy and light work these trends are not sustained. Table 6 further illustrates the point that

FIG. 1.—Absence rates of men on jobs where the heaviness and continuity of working differed.

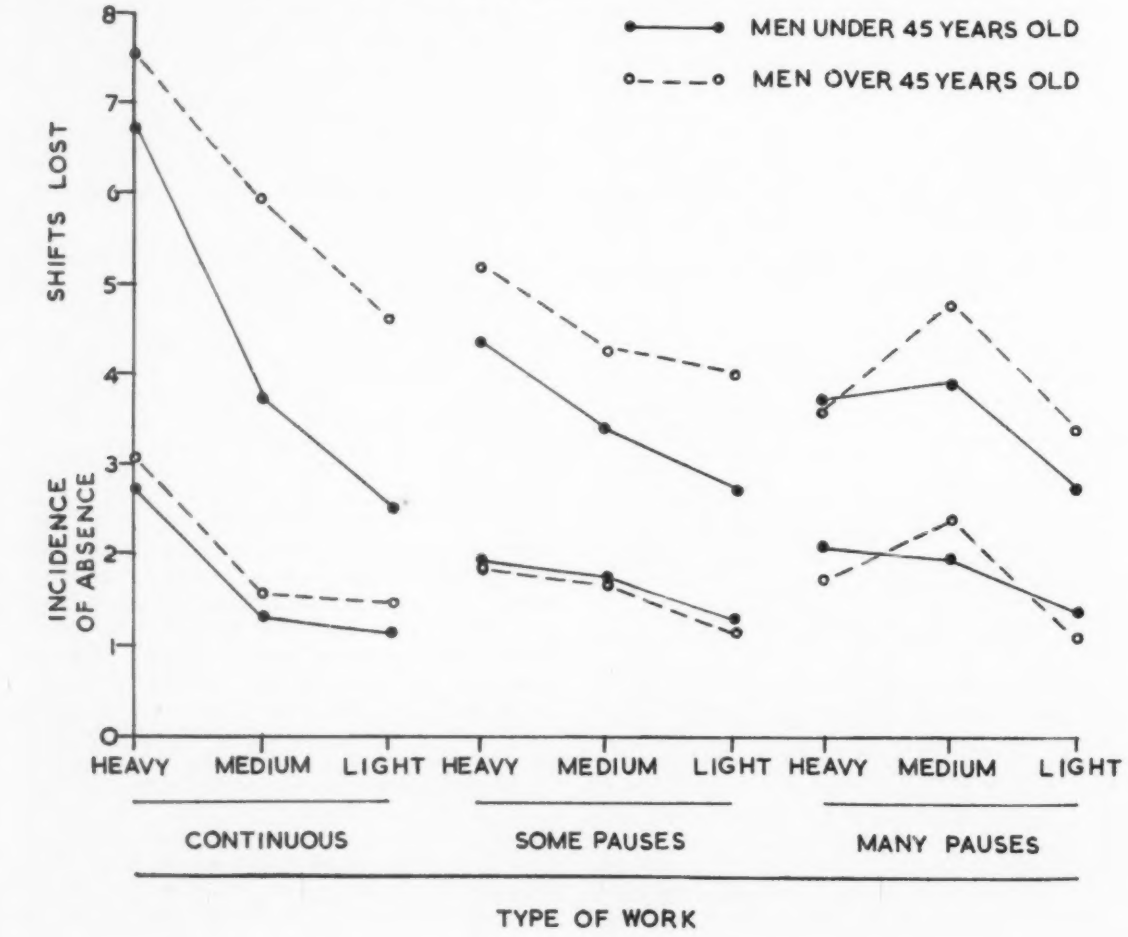

TABLE 6

ABSENCE RATES OF MEN ON JOBS WITH DIFFERING HEAVINESS AND CONTINUITY OF WORKING

Type of Work	% Shifts Lost			% Incidence of Absence			No. of Men		
	Heavy Work	Medium Heavy	Light Work	Heavy Work	Medium Heavy	Light Work	Heavy Work	Medium Heavy	Light Work
Men under 45 years old									
Continuous work	6·77	3·74	2·49	2·76	1·29	1·12	76	136	145
Some pauses	4·36	3·36	2·67	1·96	1·78	1·22	121	127	125
Many pauses	3·64	3·86	2·70	2·02	1·95	1·30	45	52	37
Men over 45 years old									
Continuous work	7·55	5·99	4·60	3·04	1·54	1·42	71	58	82
Some pauses	5·19	4·22	3·94	1·87	1·64	1·10	82	93	82
Many pauses	3·51	4·74	3·39	1·68	2·36	1·04	113	40	41

continuity of working may affect the absence of older men. On continuous work, the older men had a higher incidence of absence. If shifts lost are considered for the over-45 years age group there appears to be a relation between continuity of working and absence for men in all "heaviness" categories.

Men are sometimes compensated for unfavourable conditions of work by extra payment and, although this is often small in relation to the total wage, it was necessary to ensure that there was no systematic association between pay and the heaviness or continuity of working which could confound the results. There was no relation between wage and continuity of working, but the average earnings for a full week's attendance at work of men on heavy, medium, and light jobs were 221, 199, and 206 shillings respectively. Thus, the men on heavy work received higher pay than those in the other groups. However, the relation was not systematic, and there was also no correlation between the absence rates of the groups in Table 6 and their average earnings.

The physical heaviness of the work was the only condition which showed a consistent relationship with the amount and incidence of absence in both age groups. It is important to demonstrate that the trend was general and was not attributable to a limited number of workers, for instance, the men in one firm. Accordingly, six groups were selected which differentiated the sample by shift system and/or works. Table 7 shows the numbers and percentages of men in the heaviness categories who experienced different numbers of absences in the year. Here individual differences in absence behaviour are being considered rather than group averages. The totals show that 30% of the men on heavy work and only 13% of those on light work had more than six absences in the year; conversely, 47% of the men on heavy work and 64% of the men on light work had 0-3 absences. The absences of men on medium heavy work fell between these two extremes. The difference is statistically significant.*

When the absences in each group are examined the results show that in all cases a greater proportion of the men on heavy work as compared with light work had more than six absences in the year, and

*In groups A, B, and F and the total the expected trends are regular. Chi-squared is statistically significant at the 1·0, 0·1, 5·0, and 0·1% levels respectively. In groups C, D, and E the expected trends are not consistent, and the χ^2 test was not applied.

TABLE 7

NUMBERS OF MEN ON HEAVY, MEDIUM, AND LIGHT WORK WITH VARYING NUMBERS OF ABSENCES IN THE YEAR

Groups	A			B			C			D			E			F			Total		
Works	Steel Works			Steel Works			Engineering			Both Steel Works			Both Steel Works			Engineering					
Shift System	21 + 19 Shifts			21 Shifts			5-Day Week			5½-Day Week			17 Shifts			Miscellaneous			Miscellaneous		
Type of Work	Heavy	Medium	Light	Heavy	Medium	Light	Heavy	Medium	Light	Heavy	Medium	Light	Heavy	Medium	Light	Heavy	Medium	Light	Heavy	Medium	Light
Number of Men																					
0-3 Absences	51	87	91	49	42	53	60	102	70	6	9	13	40	32	89	33	10	14	239	282	330
4-6 ,,	35	38	33	21	26	12	12	27	16	3	9	10	28	9	34	16	8	9	115	117	114
>6 ,,	27	33	11	38	14	12	18	17	17	11	30	7	12	2	16	48	11	5	154	107	68
Percentage of Men																					
0-3 Absences	45	55	67	45	51	69	67	70	68	30	19	43	50	74	64	34	34	50	47	56	64
4-6 ,,	31	24	24	19	32	16	13	18	16	15	19	33	35	21	24	16	28	32	23	23	22
>6 ,,	24	21	8	35	17	16	20	12	17	55	63	23	15	5	12	49	38	18	30	21	13

a smaller proportion had none to three absences. However, the trends are regular and statistically significant in groups A, B, and F, but not in groups C, D, and E. Men in groups A, B, and F worked in the two steel firms and the engineering works respectively. The association between the heaviness of the work and absence was not, therefore, specific to one factory.

The higher absence of men on heavy work could be due to a greater amount of sickness. This was tested in two ways: first, by considering the distribution of absences of different lengths in the heaviness categories, and, secondly, by analysing the classification of absences. The former method was more widely applicable to the data, as the classification of absence was not available for some factory groups. In the records where the absences were classified with reasonable thoroughness it was found that most absences of four to nine days' duration and nearly all absences of 10 days or longer were due to certified sickness or injury. Absences of less than four days in length included nearly all the absences without permission, leave, uncertified sickness, and a few injuries.

The number of absences of different lengths and the days lost which were due to these were tabulated for each " heaviness " category. The calculated absence rates are shown in Table 8.

In the younger age group the incidence of absences of all lengths decreases as the work becomes lighter, although the trend is more noticeable for short absences than long absences. In the older age group the incidence of short absences also decreases but the number of long-term absences remains relatively constant. The lost time rates follow a similar pattern. A possible explanation for the discrepancy in absence behaviour between the older and younger men was that the unfit had ceased to work on heavy jobs and only those older workers who were best able to undertake arduous work remained. However, it is necessary to be cautious in making such interpretations as the number of men and the number of long-term absences were small.

The classification of absence into sickness and other categories was available for a large group of workers on the 21- and 19-shift cycles (Table 7, Group A). The reasons for absence were ascertained by the foremen and timekeepers as accurately as was possible. The number of absences in the year and the average number per man are shown in Table 9 for workers in the " heaviness " categories. The absences are grouped into those which were due to sickness and injury, and to " other reasons " (absence with or without permission and uncertified sickness).

TABLE 8

ABSENCE RATES DUE TO ABSENCES OF DIFFERENT LENGTHS OF MEN ON JOBS WITH DIFFERING HEAVINESS OF WORK

Length of Absence	% Shifts Lost			% Incidence of Absence		
	Heavy Work	Medium Heavy	Light Work	Heavy Work	Medium Heavy	Light Work
Men under 45 years old						
1 day	1·63	1·20	0·89	1·63	1·20	0·89
2-4	0·94	0·63	0·40	0·39	0·27	0·17
5-9	0·65	0·47	0·45	0·11	0·08	0·07
>9	1·70	1·30	0·85	0·08	0·06	0·05
No. of Men	242	315	307	—	—	—
Men over 45 years old						
1 day	1·52	1·33	0·83	1·52	1·33	0·83
2-4	0·96	0·63	0·52	0·39	0·27	0·21
5-9	0·52	0·50	0·53	0·09	0·08	0·09
>9	2·02	2·38	2·22	0·08	0·09	0·09
No. of Men	266	191	205	—	—	—

TABLE 9

INCIDENCE OF ABSENCE DUE TO SICKNESS OR INJURY AND OTHER REASONS OF MEN ON JOBS WITH DIFFERING HEAVINESS OF WORK

Type of Work	Men under 45 Years Old			Men over 45 Years Old		
	Heavy Work	Medium Heavy	Light Work	Heavy Work	Medium Heavy	Light Work
No. of Men	54	107	73	59	51	62
Number of Absences						
Sickness or Injury	16	39	19	27	16	38
Other Reasons	242	406	194	305	242	174
Number of Absences per Man						
Sickness or Injury	0·30	0·36	0·26	0·46	0·31	0·61
Other Reasons	4·48	3·79	2·66	5·17	4·75	2·81

The table shows that there are fewer absences in the " other reasons " category as the work became lighter,* but there is no consistent relationship between the incidence of sickness absence and injury and the heaviness of the work.

Discussion

The results from this study showed that there was a relationship between absence and the heaviness of the work, as assessed by the managers and foremen. Among the younger men the number of absences of all lengths increased as the work became heavier, and all except the longer absences increased among the older men. Examination of the "reasons" for absence, as classified in one firm, showed no significant relationship between the incidence of sickness or injury and the heaviness of the work; the relationship was predominantly due to those absences classed under " other reasons ". When the men were separated into their different factory groups and according to the shift systems they worked, the association was apparent in the three firms and on all shift systems, although it was statistically significant in some groups but not in others.

There was an interaction between the heaviness and continuity of working such that the men on continuous heavy work had high absence rates. It also appeared that the continuity of working affected the older men more than the younger.

Exposure to heat, as assessed by the managers and foremen, was associated with a decrease rather than an increase in absence rates. In one firm there was no evidence of a consistent relationship between absence and exposure to dust or fumes. These results do not exclude the possibility that on particular jobs the working conditions did affect absence, but the number of men on any single operation was too small to test this.

The findings must be evaluated in relation to other factors in the working situation, and among the most important of these was the selection and placement of the workers. If there was a tendency for less fit men to be transferred from work with adverse conditions then no association with absence was likely to emerge, but if there was a tendency for less fit workers to be placed on jobs with adverse conditions, then any trends would be exaggerated. There was evidence that both these selective processes existed, although they cannot be demonstrated quantitatively.

*For men in both age groups χ^2 is significant at the 0·1% level. Chi-squared is applied on the assumption that the observations in each cell are independent, although this is not strictly correct when a man has more than one absence.

Each of the three works had medical officers who carried out a pre-employment examination of new entrants. Those who were unfit were not placed on the more arduous jobs, and others with specific complaints were excluded from particular occupations. In addition, men who returned from a long sickness absence were medically examined before resuming work. If they were unfit to work on their previous job they would be advised to ask for a transfer.

In the iron and steel works most production jobs were manned by small groups of workers. A new entrant to a department might be started as a shift labourer. Later he would be placed on the lowest ranked job on a production process and during his working life would be promoted until he was a senior operator. The heavier jobs were often of low rank in the promotion sequence and the men would work on them relatively early in their careers. In one department the example was given of a heavy job in the open air which had been transferred to a lower position in the promotion sequence so that it could be manned by a younger worker. In a few instances where conditions were severe, operators were provided with relief men; this happened with soaking pit crane drivers who were exposed to high temperatures.

It is probable that self-selection occurred, particularly in the engineering works where there was little opportunity for promotion and men usually stayed on the same job. It is difficult to demonstrate that men who are unsuited to a job fail to take it up, or that they start work and then leave, but there was some evidence for this. Younger men had an increasing frequency of long absences as the work became heavier, but this did not occur with older men and it was suggested that only the fittest of the latter remained on heavy work.

There appeared to be selective factors which were having the opposite effect. It was difficult to recruit labour for some of the most arduous or unpleasant work, and this was particularly noticeable on obsolescent jobs which were manned by men prone to have many absences. For instance, the forge in the engineering works contained many of the heaviest jobs observed. The conditions on the puddling furnaces and the hand rolling mill differed little from those which were described by Vernon (1920). Of the 11 puddlers, seven were over 50 years old, and furnaces were idle for want of labour. The lost-time rate in the forge was 8·14%, which was the highest of any department. This illustration serves to show that on some of the heaviest jobs the labour employed was liable to have a high absence rate. However, on the whole the processes of selection reduced the probability that adverse work-

ing conditions would have long-term effects on the health of the workers. The medical supervision of placement was probably an important influence in this respect.

Conclusions

In brief, then, the results from the investigation suggest that where arduous physical work is still practised men will have more absence than those employed on lighter work. In this study the trend was more pronounced for short absences than for long absences. These findings must be seen in relation to the pre-employment medical examination of the men, the transfer of men who were no longer physically suited to heavy work to other jobs, and the system of promotion in the iron and steel works which meant that many men worked on a variety of occupations throughout their careers and experienced varied conditions of work. In a few occupations selection was probably in the opposite direction and older men were working in conditions for which younger men would be better suited. It is difficult to describe the selective processes in industry or to assess their effects. It is probable that some, such as the movement of the unfit to easier work, are general factors, but others, such as the effects of promotion, are specific to an industry or to an individual firm. Belbin (1955) has given a detailed discussion of this question in relation to the proportion of older people on heavy work.

The continuity of working also appeared to be related to absence, although the result was less striking than with heavy work. Men in occupations which involved both continuous and heavy work had higher absence rates than workers on other jobs. Older men on continuous work lost more time than those who worked intermittently throughout the shift, but men under 45 years old were not affected in this way. Welford (1951) found that on work which was paced the proportion of older workers employed was less than on operations which were unpaced, and Richardson (1953) showed that older men tended to move from work where there was speed stress. Although all the occupations which involved continuous work were not paced the findings here tend to confirm the unsuitability of this type of work as age increases.

Absence statistics can demonstrate the association between the heaviness or continuity of working and absence, but they can reveal little about the causes of the association. These could include the direct effects of fatigue, a disinclination to attend when the work was arduous or uncomfortable, inability to tolerate heavy work when slightly " off colour " or convalescing, or differences in the selection of the men doing the work. Probably physical and psychological states contributed to the result, but it is not possible here to determine their relative importance.

Exposure to heat was associated with a decrease rather than an increase in absence rates, although the reasons for this were unknown. In the one firm where an analysis was made, exposure to dust and fumes was not related to absence, but owing to the few workers involved in the comparisons this cannot be considered as conclusive.

Summary

The absence records of selected samples of men employed in an engineering firm and two iron and steel works were examined to test for associations between the physical conditions of work and absence. The conditions of work were assessed by the managers and foremen using rating and ranking techniques. The physical heaviness, continuity of working, temperature, and exposure to dust and fumes which were associated with the occupations were assessed by these methods. There was a relationship between the physical heaviness of the work and absence. The continuity of working in combination with other factors was also associated with absence. There was no increase in absence with exposure to heat, dust, or fumes. The results are discussed in relation to the selective factors operating.

This work has been under the general direction of Dr. R. B. Buzzard and Mr. J. W. Whitfield to whom we are greatly indebted for help and advice. We are also grateful to our colleagues at University College, London, for valuable criticism. We wish to thank the members of the firms we visited for their cooperation, and we are especially grateful to the medical officers and labour managers.

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AZO DYES AND HEINZ BODIES

BY

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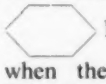
No general hypothesis has been advanced to explain the underlying cause of the appearance of Heinz bodies in erythrocytes. The initial observation of Riess (1882) on a case of potassium chlorate poisoning was followed by that of Heinz (1890) who administered phenylhydrazine to animals. Since then Heinz bodies have been induced by a great variety of substances, principally aromatic and aliphatic nitro-compounds, aromatic amines and organic (notably azo) dyestuffs, a miscellaneous group of organic nitrogen-free compounds (*e.g.*, naphthalene, 2 : 4 dichlorphenol, ascorbic acid), and a number of inorganic substances (*e.g.*, sodium nitrite, sodium sulphite, potassium dichromate, arsine). Heinz bodies are also found normally in cats (Hecht and Wingler, 1952) and their appearance has been observed after splenectomy in animals (Schilling, 1921; Freifeld, Schilowa, and Ludwinowsky, 1937) and in human subjects (Zadek and Burg, 1930; Selwyn, 1955). The substance of Heinz bodies has been thought by many to originate from haemoglobin rather than the cell stroma, and recently Beaven and White (1954) have demonstrated that it is spectroscopically similar to insoluble "green haemoglobin" which is described as being "complex, containing haems and other iron-containing pigments bound to denatured globin". Associated with the appearance of Heinz bodies, though not invariably, are anaemia, methaemoglobinaemia, and verdohaemoglobinaemia: these and other topics have been exhaustively reviewed by Fertman and Fertman (1955).

The use of azo dyes for the colouring of food has led to some preoccupation regarding the possible carcinogenic and toxic effects of the dyes or of the products resulting from reduction-fission at the azo linkage. The current need for more information on dye toxicity is emphasized in the report on colouring matters issued by the Food Standards Committee of the Ministry of Food (1954) wherein reference is made to the work of Hecht and Wingler (1952). These authors point out that although fission products such as aniline, toluidine, or xylidine may not have been proved to be carcinogenic, their other known toxic properties rule out the use of the parent dye in food. A suitable dye might be assessed from this point of view by estimation of the degree of methaemoglobinaemia produced, but Hecht and Wingler (*loc.cit.*) advocate instead the examination of the blood for Heinz bodies, as this procedure is simpler and more sensitive. These authors reported that no Heinz bodies were produced by azo dyes of the type



(R = sulphonated aromatic component)

when the aniline component was sulphonated. This finding accords well with the generally accepted view that sulphonation has a detoxicating effect, and enhances the value of the Heinz body test as an indication of the presence of, for example, free amines. In a later paper, Wingler (1953) found that methylation at the para position on the aniline component of benzene-azo-naphthol 6 and 6 : 8 sulphonates likewise removes Heinz body-forming activity.

In the work described in this paper the activity of eight azo dyes (Table 1) has been observed in order to compare the effect of substituent groups in the benzene-azo-naphthalene nucleus. The dyes were administered in the food since an ultimate object has been to assess the significance of Heinz body formation in the problem of food colours for human consumption.

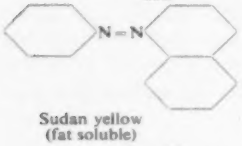
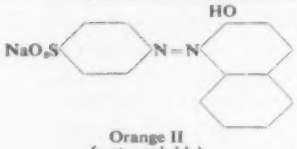
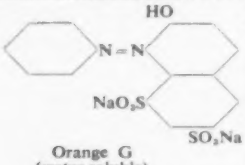
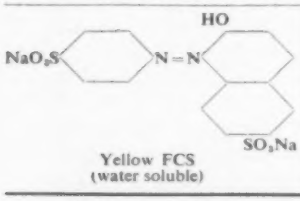
Method

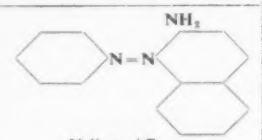
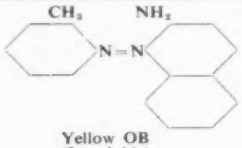
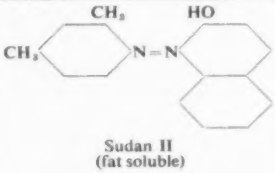
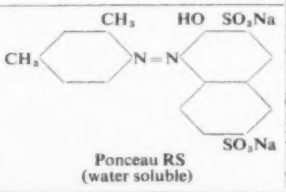
For each dye tested, 10 male rats weighing 150 to 200 g. were used. Rat cake No. 86* milled to a coarse powder, was mixed with the dye to give a concentration of 2 mM. pure dye/100 g. food (equivalent to 0·5% Sudan yellow); a known proportion of inorganic diluents was present in the dye samples and was allowed for. The daily food intake was limited to 60 g./kg. mean body weight in order to avoid the variation which occurs, due to differences in palatability, when larger amounts

*North Eastern Agricultural Cooperative Society Ltd.

TABLE 1

INDIVIDUAL HEINZ BODY RESPONSES OF RATS FED AZO DYES IN THE DIET

	Heinz Body Induction Index (H)	Peak Heinz Body Incidence (% R.B.C.s)	Time to Reach Peak Incidence (days)
 Sudan yellow (fat soluble)	3·8	43	12
	3·7	44	13
	2·9	29	10
	3·6	40	11
	4·1	49	12
	4·7	47	10
	3·3	40	12
	2·1	27	13
	5·9	53	9
	4·9	54	11
Means	[3·9]	42·6	11·3
Standard error	0·34		
 Orange II (water soluble)	45	99	4
	28	78	4
	32	99	4
	50	100	2
	24	95	4
	49	98	2
	15	91	6
	33	99	3
	25	100	5
	50	100	2
Means	[35]	97·9	3·6
Standard error	4·0		
 Orange G (water soluble)	3·7	26	7
	11·7	76	9
	13·7	89	7
	4·0	28	8
	13·3	87	7
	13·8	83	6
	4·1	50	13
	11·3	77	7
	10·6	75	7
	8·0	58	8
Means	[9·4]	64·9	7·9
Standard error	1·31		
 Yellow FCS (water soluble)	No Heinz Bodies		

	Heinz Body Induction Index (H)	Peak Heinz Body Incidence (% R.B.C.s)	Time to Reach Peak Incidence (days)
 Yellow AB (fat soluble)	5·9	47	8
	2·5	25	10
	6·1	49	8
	5·0	40	8
	4·5	36	8
	8·0	56	7
	4·7	38	8
	5·4	43	8
	9·0	63	7
	4·6	46	10
Means	[5·6]	44·3	8·2
Standard error	0·58		
 Yellow OB (fat soluble)	0·8	15	18
	1·2	22	18
	1·0	18	18
	1·3	23	18
	0·7	13	18
	1·6	29	18
	0·9	16	18
	0·6	12	18
	0·4	7	18
	0·9	17	18
Means	[0·9]	17·2	18·0
Standard error	0·11		
 Sudan II (fat soluble)	1·9	38	20
	2·9	58	20
	1·7	39	29
	1·2	22	18
	1·9	33	20
	2·1	40	19
	2·6	52	20
	1·9	34	18
	2·4	50	21
	2·3	44	19
Means	[2·1]	40·0	20·4
Standard error	0·15		
 Ponceau RS (water soluble)	No Heinz Bodies		

All dyes were fed at a concentration of 2 mM/100 g. food, and the total food intake controlled to obtain approximately equimolecular dye ingestion. The figures for Sudan yellow itself are slightly low, as, owing to unpalatability, about 12% of the dye-food mixture was rejected.

are available to the animals. Spillage of food, which becomes a problem when unpalatable dyes are fed, was avoided by use of specially designed containers which reduced this loss to not more than 0·1%. By these means ingestion of equimolecular quantities of dyes per unit body weight per day were obtained, thus enabling the Heinz body responses to the different dyes to be compared

Heinz body counts were made at frequent intervals, especially during the period near the peak incidence. To one drop of methyl violet stain (half-saturated solution in normal saline containing 0·2% sodium citrate) on a slide, was added one-quarter this volume of tail blood on the corner of a coverslip: after mixing, the coverslip was released and the edges sealed with " vaseline ".

At least 300 red cells were counted on each occasion using ×855 magnification. The greatest care was taken to distinguish Howell-Jolly bodies and reticulocytes, and to ensure that the field under examination was adequately stained to show up the smaller Heinz bodies. Blood from normal rats was not found to contain Heinz bodies.

Results

The Heinz Body Response.—From day-to-day observation of some 150 rats receiving dyes continuously in the diet, it can be said that the Heinz body level usually takes the following course: there is first a latent period between the beginning of

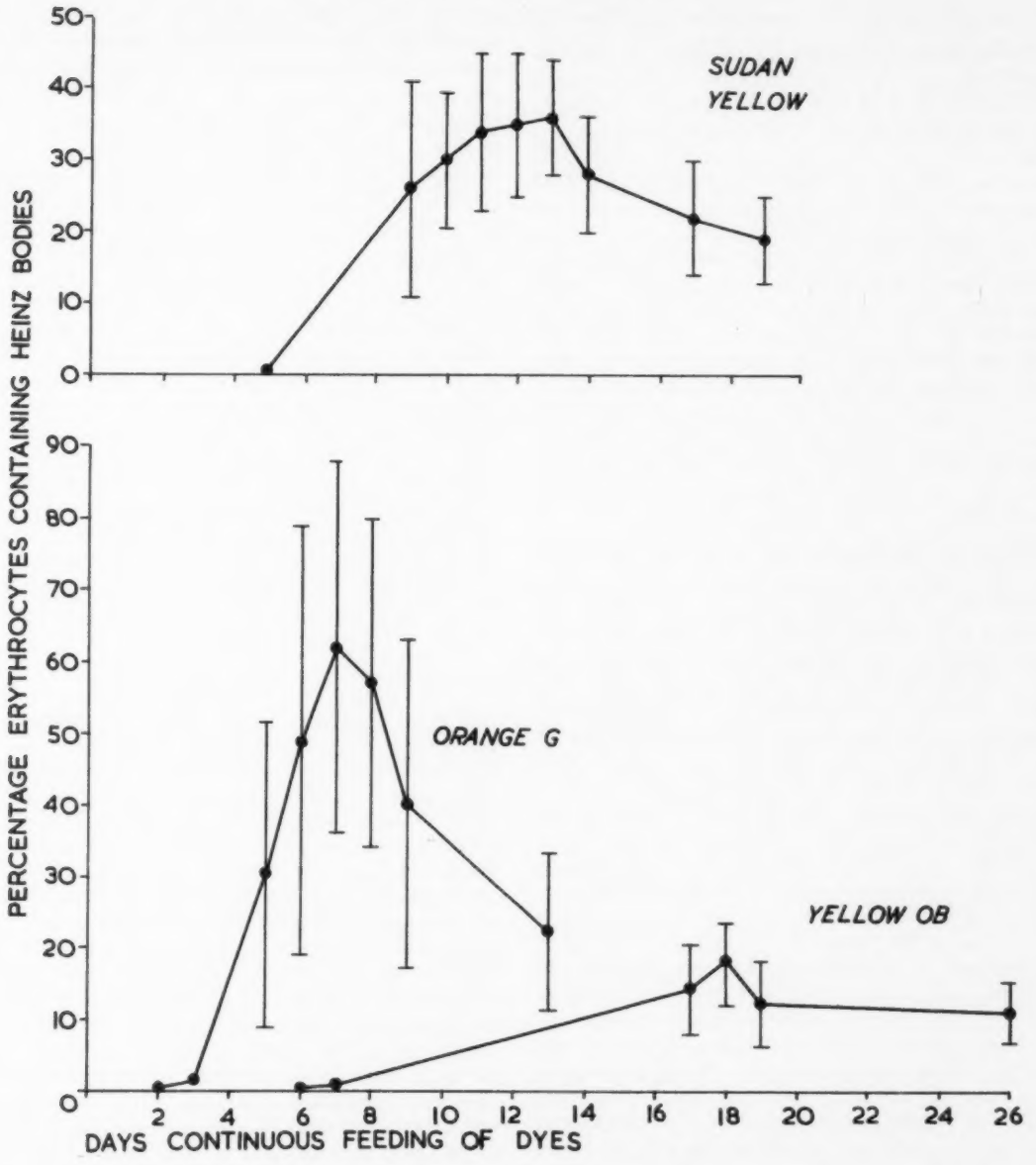


FIG. 1.—The proportion of erythrocytes containing Heinz bodies in groups of 10 rats ingesting in equimolecular quantities either Sudan yellow, orange G, or yellow OB. Each point is the mean value; the vertical line represents ± the standard deviation. These dyes have been chosen to show the large differences in the form of the response, yet the same general pattern is discernible in each case, namely, a latent period, relatively rapid rise to a peak, and a slower fall. Thereafter a fluctuating lower level is maintained so long as the dye is given.

ingestion of dye and the appearance of Heinz bodies in the blood, and this may last one or several days depending on the dye, its concentration, and the individual response of the animal; there follows a relatively rapid rise to a peak frequency of Heinz bodies and this is followed by a fall to a fluctuating lower level which is maintained so long as the dye is consumed. Fig. 1 shows the course of the mean Heinz body level in groups of 10 rats ingesting, in equimolecular quantities, Sudan yellow, orange

G, or yellow OB (for structures see Table 1).

Comparison of Heinz Body Responses.—In attempting to compare the sizes of the Heinz body responses it is evident that as well as the maximum incidence of Heinz body-bearing erythrocytes attained, the time taken, *i.e.*, the total dose in gram-molecules, must be taken into account. In order to obtain an expression for the true Heinz body-forming potency of one dye relative to that of another, an arbitrary "Heinz body induction index" (H) has been used: this is the highest quotient obtainable by dividing the Heinz body incidence by the time taken to reach it at a stated feeding rate. This value and also the peak Heinz body incidence, with the time taken to reach it, is given for each animal in Table 1. It will be appreciated that the highest quotient is not always obtained from the peak Heinz body incidence: thus an incidence of 80% on day 4 will give a higher quotient and indicate a higher potency than 85% on day 5.

Effect of Sulphonation and of Methylation.—It is seen in Table 1 that p-sulphonation of the aniline component of benzene-azo-2-naphthol (Sudan yellow) to give orange II greatly increases the Heinz body response : the value of H is raised from 3·9 to 35. Disulphonation (6 : 8) of the naphthol component instead, to give orange G, also increases the response, in this case to 9·4. But monosulphonation of both aniline and naphthol components gives yellow FCS, which is completely ineffective as a Heinz body inducer. The results for Sudan II and Ponceau RS show that unilateral sulphonation is sufficient to abolish the Heinz body-inducing property if the contralateral component relative to the azo link is dimethylated.

Wingler (1953), using cats, found ortho- or para-methylation to abolish activity in the water-soluble benzene azo-2-naphthol-6 and 6 : 8 sulphonates. The effect of methylation of the benzene component of benzene-azo-2-naphthol (Sudan yellow) is seen (Table 1) in the results for Sudan II, and of methylation of benzene-azo-2-naphthylamine (yellow AB) is seen in the figures for yellow OB. In the former case methylation greatly delays the attainment of the peak value, which is not altered, and reduces the index H from 3·9 to 2·1: application of the t test to this result shows a significant difference ($P < 0.005$). In the latter case, there is both delay and a smaller peak: H falls from 5·6 to 0·9. These findings are the more valid since solubility complications are excluded, all four dyes being fat soluble and water insoluble.

The effect of p-sulphonation or of p-methylation of aniline on the Heinz body-producing activity of this substance has been observed in a few animals in the course of the present work. This is of interest since aniline or a homologue of aniline will be an expected primary metabolite resulting from reductive fission at the azo link. It was found that the mean peak Heinz body response to feeding 0·1% aniline in the diet was 24% in six days, but when sulphanilic acid, at four times the molecular concentration of 0·1% aniline, was given in the diet no Heinz bodies were seen. On the other hand, p-toluidine at a molecular concentration equal to that of 0·1% aniline produced a peak response of 48% after 15 days: this result contrasts with Wingler's finding (1953) that only the m-isomer causes Heinz bodies; however, he used a much smaller dose injected daily in cats for only 10 days. Daniel (1956) identified aniline in the urine of rabbits given Sudan yellow (0·5 g./kg.) although 85% of the material in the urine (which was 51% of the dose administered) could be accounted for as p-aminophenol and 1-amino-2-naphthol. The formation of Heinz bodies in rats, however, is not due to p-aminophenol, for neither feeding at twice the molecular concentration of 0·1% aniline for 23 days, nor subcutaneous injection at 240 mg./kg. per day for six days caused them to appear.

Discussion

Evidence against Heinz Body Formation by Unchanged Dye.—Heinz bodies are formed only in erythrocytes and are not found in immature precursors. The question arises as to whether the active agents in the plasma are the dyes or their products resulting from reductive fission at the azo link. While a direct answer cannot be given, some incidental observations bearing on this have been made which suggest that the dyes themselves are not responsible. The fat-soluble dyes referred to in Table 1 cause intense coloration of the plasma, whereas the plasma of rats receiving the water-soluble dyes, with the possible exception of orange II, are strikingly free from colour: this also applies to the water-soluble dye azo geranine* which leads to vigorous Heinz body formation. If the dyes as such were the effective agents, it would be expected that those which are not seen in the plasma would be relatively inactive, but, in fact, Table 1 shows that the two water-soluble dyes quoted give much higher values for H (35 and 9·4) than the fat-soluble dyes (5·6, 3·9, 2·1, and 1·0). On the other hand, where a dye is found in the plasma it would be expected to be found in the blood cell, since this is the site of Heinz body formation, but, in fact, the dye appears to be excluded from the red cell, for ether extracts

*Disodium salt of 8-acetamido-2-benzeneazo-1-naphthol-3:6 disulphonic acid.

of packed erythrocytes from rats fed the fat-soluble Sudan yellow or yellow AB show no colour, although these dyes produce particularly intense plasma coloration.

Heinz Body Test and Carcinogenicity.—Wingler (1953), referring to the possible carcinogenicity of dyestuffs, has stated that the failure of a dye to produce Heinz bodies may be taken as proof that no physiologically active fission products have arisen in the blood. While dubious carcinogens such as aniline and toluidine are certainly Heinz body formers, the same cannot be said for β-naphthylamine which, although a potent carcinogen, has been found under the conditions of the present study to have no Heinz body-producing activity. Wingler compares the loss of carcinogenicity which occurs when dimethylamino-azo-benzene is methylated at the p-benzene position with the loss of Heinz body-forming activity of azo dyes by methylation, but feels that no direct relation between a positive Heinz body test and carcinogenic effect exists. This view is confirmed by the following evidence: Frodsham (1956) fed azo geranine or red 10 BS* in the diet at a concentration of 1·5% each dye, to 20 rats, for a period of two years without finding tumours; Allmark, Grice, and Lu (1955) after feeding yellow AB or yellow OB (0·3%) in the diet, each to a total of 50 rats for 65 weeks, found only two neoplasms in the former case and none in the latter. But in the course of the present work all these dyes have been found to produce Heinz bodies, particularly the former two, which are very active.

Changes Concurrent with Presence of Heinz Bodies.—Irrespective of the value of the Heinz body test as a very sensitive indicator of the presence in the blood of certain toxic amines and of many other substances, the question remains as to whether the presence of Heinz bodies as such has any adverse effect on the animal. Rats eating about 1 to 1·5 g./kg./day azo geranine for 75 days showed no external symptoms apart from a slight cyanotic appearance despite a mean peak Heinz body level of 80% falling to a maintained level of 30%. Internal changes included a moderate though well-controlled anaemia, pronounced reticulocytosis, and splenomegaly: the anaemia and reticulocytosis were presumably due to the destruction of affected erythrocytes by the spleen. The maintenance of a Heinz body level as a result of regular ingestion of an otherwise harmless substance must therefore lead to a state of chronic hyperactivity of the reticuloendothelial and haemopoietic systems. In the rats, a return to ordinary diet resulted in a return to normal values within two weeks, apart from a slight compensatory polycythaemia which remained for months; but whether irreversible changes would not occur if such a substance were taken during a much longer period is not known. Further data on these topics will be published.

*Disodium salt of 8-amino-2-phenylazo-1-naphthol-3 : 6-disulphonic acid.

Summary

1. The induction of Heinz bodies in rats by azo dyes has been studied in relation to the effect of different substituent groups attached to the benzene-azo-naphthalene nucleus. Eight dyes having this nucleus in common were fed continuously at equimolecular rates by admixture in the diet, each dye to a group of 10 rats, and the blood examined at intervals for Heinz bodies.

2. Although the magnitude and timing of the Heinz body response to different dyes varied greatly, the same basic pattern was observed in each case: a latent period, then a relatively rapid rise to a peak concentration of affected erythrocytes, followed by a slower fall to a fluctuating lower level which was maintained so long as the dye was given.

3. An arbitrary "Heinz body induction index" has been used to facilitate the comparison of the true potencies of the dyes irrespective of their different rates of accumulation.

4. It was found that sulphonation of the benzene-azo-naphthol molecule in either component increased Heinz body induction, but sulphonation of both components abolished it. Methylation of the phenyl group in benzene-azo-naphthol and in benzene-azo-naphthylamine decreased Heinz body induction. Complete loss of activity was obtained by methylation of the phenyl component and sulphonation of the naphthol group in addition in benzene-azo-naphthol. Sulphonation was also found to remove the Heinz body-producing activity of aniline, which is an expected dye metabolite.

5. The coloration of the plasma by ingested fat-soluble dyes but not by water-soluble dyes shows no correlation with Heinz body-producing activity and suggests, along with other evidence, that dye metabolites rather than the dyes as such are the effective agents.

6. With regard to carcinogenicity of dyestuffs and Wingler's (1953) proposal that an absence of Heinz bodies showed an absence of physiologically active amines, the carcinogenic amine β-naphthylamine was not found to cause Heinz bodies. Four non-carcinogenic dyes were shown to cause Heinz bodies.

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German and criticism of the manuscript. I am also indebted to Mr. D. W. Swanston for valued technical assistance.

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THE JULY (1957) ISSUE

The July (1957) issue contains the following papers:—

Assessing the Health of the Industrial Worker. By R. S. F. Schilling.

The Control of Industrial Bladder Tumours. By T. S. Scott and M. H. C. Williams.

A Routine Method for the Preparation of the Cells of Urine. By Philip Rofe.

The Testing of Life-jackets. By R. R. Macintosh and E. A. Pask.

A Study of the Thermal Environment in Non-ferrous Foundries. By D. Turner.

Gamma Radiography in Industry. By J. P. W. Hughes and O. Shaw.

The Corrosion of Metal by Palmar Sweat. By K. J. Collins.

Excretion of Urinary Coproporphyrin in Lead Poisoning. Parts 1 and 2. By Václav Holeček.

Tracheotomy in Major Chest Injuries. By S. A. Gueukdjian.

Miscellanea:

A House-Surgeon's Observations on Bronchitis in North Staffordshire Pottery Workers in 1864. By A. Meiklejohn.

" A Study of Attitudes to Factory Work ": A Review. By H. G. Maule.

The British Occupational Hygiene Society.

Book Reviews.

A number of copies are still available and may be obtained from the Publishing Manager, British Medical Association, Tavistock Square, W.C.1, price 12s. 6d.

Brit. J. industr. Med., 1957, **14**, 281.

EXPERIENCE OF PULHEEMS IN THE 1952 ARMY INTAKE

BY

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It has long been the custom for the armed Services to grade recruits medically before accepting them for training. Since the war of 1939/45 an elaborate system of grading known as PULHEEMS has been used, and it is now possible to see what it portrays of the young men who have been joining the Forces.

Entrants to the Services are given three medical examinations within five or six months. First a provisional assessment is made by the Ministry of Labour and National Service; then when they are called up, and subsequently at the end of basic training, the Services themselves carry out further examinations of entrants to ensure their fitness for military duties.

The PULHEEMS system codifies the results of the examination by allotting numbers to each of a few descriptive " qualities " whose initials form the title of the system. The only strictly objective qualities are the central letters, *H* for hearing and *EE* for eyes, where the results of standard tests are registered on a well-defined scale. This leaves the tail of the word, *M* (mental capacity), and *S* (emotional stability), as it were the capacity for thought and feeling, and the head of the word where *U* and *L* stand for upper and lower limbs, and *P* for physique; the latter is associated to some extent with the other qualities. In all these qualities of the head and tail the assessment is of functional capacity to perform a duty. The duty is not specific, and relates to two requirements, eventual fitness for combat and for service in any climate. Standards are changed where appropriate, as for women, and during service perhaps for officers, but we shall not be concerned with these here.

The present analysis is of the PULHEEMS assessment on call-up of the entire Army intake of 1952 and represents only the fittest 80% of the young male population called up for National Service in that year. With this limitation it is a complete national coverage and can be used as a standard reference for any special group whose physical qualities are to be assessed.

Discharges from the Army due to re-assessment in the first weeks of training are discussed, and include an important group of men who deteriorated in condition since they were first examined. It is shown that the large number of theoretically possible grades reduces to a moderate number in practice, corresponding to recognized defects. The relative importance of these and their likely disposal are examined. Certain associations are shown to exist, as, for example, between hearing and emotional stability.

The Main PULHEEMS Categories

The numerical scale runs from 1 to 8, but the full gradation is not used for each quality, neither is there equivalence throughout for a particular number. The simplest is that for acuteness of vision, where the scale corresponds to the divisions of Snellen's test types for each eye separately. Hearing is similarly straightforward, but the gradation is based on a five-point scale, proceeding directly from 1, 2, 3 to 7, 8.

For the rest, the PLUMS qualities, we may dismiss 8 as recording unfitness for service in any form, and note that 1 represents an above-average prognostication for the time when a man is fully trained (it is never used for *M* or *S*).

We are left then with 2, which is the average man (in the colloquial sense) fully suitable as a combatant, and the restricted grades of 3, below average, and 7, with markedly diminished functional capacity. The numbers 4, 5, and 6 are used only for *P*, and *S* (6 only), and denote a climatic restriction, so that 4 and 5 imply service in a temperate climate (but fully combatant, corresponding to 1 and 2), while 6 similarly confines the already restricted 3 also to a temperate climate. The number 7 in *P*, *M*, or *S* automatically implies service in the United Kingdom

only, because of a need for treatment or potentiality for breakdown.

The Ministry of Labour and National Service uses the categories Grades I-IV to advise the individual of his state of fitness at the first examination. These correspond to the PLUMS qualities as follows: any 8 implies a Grade IV, as does an *M*7 or an *S*6 or 7. Other 7s are Grade III, as are *M*3 and *P*4, 5, and 6. Then any other 3 but *M*3 is Grade II, and any Pulheems " profile " without a 3 or worse is Grade I. The Grade II (*a*) (feet) is used when the only 3 recorded is under *L*.

There is no complication about *H*, which follows the same categories as *U* and *L*, but the eyes have a special notation which will be described more fully later on. There is no Grade III for eyes, although there is a Grade IV.

Table 1, recording the results of examinations carried out on call-up, shows the numbers analysed according to the Ministry of Labour and National Service grades, ignoring *EE*, that is to say, certain of those in Grade I may in reality be of a lower grade when vision is taken into account, and so on.

TABLE 1

MINISTRY OF LABOUR CATEGORIES OF ARMY INTAKE FOR 1952

Grade I	136,397
Grade II	20,028
Grade II (*a*) (feet) (4,325)	
Grade III	8,805
Grade IV	892
(not 8) (377)	
Total	166,122

It is known that about one in six men in 1952 were rejected at the original examination by the Ministry of Labour and National Service, and Table 1 therefore represents only the fitter men who had already passed this test. Those in Grade IV in Table 1 may represent a disagreement with the earlier assessment, or a genuine deterioration in condition; in the latter case, the grading on call-up may in fact be higher than that shown in Table 1, where the results of medical boards during the first weeks of service have been incorporated. It will be seen that Grade I men formed 82% of the intake, and Grade II men 12%, about one-fifth of them on the ground of foot conditions only.

In reflecting upon the physical condition of young men in the country as a whole, taking into account those rejected by the Ministry of Labour and National Service, the picture is roughly as follows:

Grade I (70%)	fit for service everywhere
Grade II (10%)	restricted (but not as to climate)
Grade III (10%)	limited usefulness
Grade IV (10%)	unfit for service

About half of those in Grade III were called up in 1952. (Recruitment of *M*3 ceased in 1954, and of all Grade III in 1956.)

About 1% of recruits were discharged from the Army on being re-assessed in their first weeks of training. The rates (per 1,000 intake in 1952) are given in Table 2.

TABLE 2

DISCHARGES FROM ARMY DURING FIRST WEEKS OF TRAINING

Grade I	1·3	
Grade II	21·5	
Grade II (*a*) (feet)	2·8	
Grade III	51·6	133·9
Grade IV	946·2	
Total		11·5

In describing the medical categories not by this simple four-grade system but under the PULHEEMS qualities, the number of possible combinations becomes quite large, although many of them do not occur in practice. One simplification is achieved later by analysing *EE* separately, and another by amalgamating degrees 1 and 2 and also 4 and 5. When this was undertaken, the great majority of the intake fell into groups as follows in Table 3.

TABLE 3

MAIN PULHEEMS CATEGORIES OF ARMY INTAKE FOR 1952

		Total in Grades	Total Intake
Grade I (all 2s)		136,397	136,397
Grade II			
*L*3	4,325		
*P*3	9,843		
*P*3*L*3	1,939		
*U*3 or *P*3*U*3	688		
*H*3 or *P*3*H*3	902		
*S*3 or *P*3*S*3	1,955		
		19,652	20,028
Grade III			
*M*3	2,607		
*P*5	2,484		
*P*6	1,012		
*P*3*L*7	857		
		6,960	8,805
Grade IV			
*P*8	187		
*M*7	103		
*S*6. 7 or 8	263		
		553	892
		163,562	166,122

It is surprising that over 98% of the intake should fall into these 14 simple categories when there are many thousands of possible combinations of categories.

Defects of locomotion restricted the capacity to serve of a large number, about a third of those in Grade II. The borderline group in Grade III, men who are with difficulty found jobs, are mainly below average mentally (*M*3), or suffer from some disease which makes a tropical climate inadvisable (*P*5 and 6).

Pulheems Qualities Considered Singly

There is much to be learned from a straightforward summary in which each quality is allotted a category irrespective of its cross-associations. In category 1 the numbers were as follows:

P	873
U	1,650
L	1,461
H	9,683

It is clear that this category is most useful for the quality *H*, where it describes the greatest acuteness of hearing, whereas under *P*, with the recruit's training yet to come, few examining doctors state that they expect him to attain category 1.

The discharges during selection procedure are related to the intake as denominator, and expressed as rates per thousand in Table 4. Category 8 is excluded.

TABLE 4

DISCHARGES FROM ARMY DURING FIRST WEEKS OF SERVICE OF INTAKE FOR 1952

Degree	*P*	*U*	*L*	*H*	*M*	*S*
1	4·6	4·8	5·5	15·1		
1, 2	6·7	11·0	10·1	11·1	9·6	7·4
3	21·4	31·6	18·6	44·6	59·9	138·9
4, 5	23·8					
6	36·3					111·1
7	604·2	662·2	100·5	76·5	993·5	844·0

Those described by *M*7 are all Grade IV, of course, but so also are those by *S*6 and *S*7, and the fact that not all of these were automatically discharged is presumably due to the retention standard being lower than the entry standard in certain corps. There may have been a desire to find a billet for some difficult cases.

When a comparison is made with the discharge rates under Grades I and IV (Table 2) it is seen that Grade I has the low rate of 1·3 per 1,000. This apparent discrepancy arises because Table 4 includes discharges under qualities other than those indicated in the column headings.

It is interesting to note that two-thirds of all those in *U*7 were discharged, and this was not through association with a degree 8 in any other quality. *P* is highly associated with other qualities, but not with other 8s in the case of *P*7, and in fact there is approximately the same high rate for *P*7 on its own, *i.e.*, combined with degree 2 in the other qualities.

An unusual feature appears in the quality *H*. With the other qualities the discharges are lowest for degree 1, but in the case of *H* this is not so; the keenest hearers have more discharges per 1,000 than the second category, which comprises the majority of the intake.

EE: Eyes

The eight degrees of this quality correspond as follows to the Snellen visual standards, the right eye being given first.

1	6/6 or better
2	6/9
3	6/12
4	6/18
5	6/24
6	6/36
7	6/60
8	less than 6/60

For each eye the uncorrected and corrected vision are shown separately in the Pulheems record. Diseases of the eye are assessed under the *P* quality; only the effect on vision is recorded in the *EE* quality.

The number of possible combinations is again very large, and this time there is not the same limitation to only a few in practice. It is impracticable to tabulate visual standards in parallel with the other Pulheems qualities.

Each row of Fig. 1 gives the standards of the right eye, and each column the standards of the left eye. Thus there were 1,155 recruits whose uncorrected vision in the right eye was 2 (6/9), and in the left eye 3 (6/12).

The standard of vision corresponding to Grade I is a minimum of degree 3 in each eye when corrected, and almost 97% are graded I for vision. The minimum standard for Grade II is degree 5 (corrected) in each eye, or as low as 7 in one eye provided that the other is at least 3. Five thousand one hundred and twelve recruits, or about 3%, were in Grade II for vision, but there is no Grade III for vision, and the remaining few were in Grade IV. Not all of these would be automatically rejected for Army service as there is a special provision for those with monocular vision.

The most striking feature of Table 5 is the lack of symmetry between right and left vision. If the difference between a symmetrical pair is judged by a standard error obtained from the square root of their sum, the following discrepancies are obtained between numbers of men with right and left vision.

These differences cannot be dismissed as fortuitous.

TABLE 5

LEFT AND RIGHT VISION

(2 1)	vision	exceeds	(1 2)	vision	by	four	standard	errors
(1 4)	,,	,,	(4 1)	,,	,,	two	,,	,,
(1 6)	,,	,,	(6 1)	,,	,,	three	,,	,,
(1 7)	,,	,,	(7 1)	,,	,,	three	,,	,,
(2 7)	,,	,,	(7 2)	,,	,,	two	,,	,,
(7 8)	,,	,,	(8 7)	,,	,,	two	,,	,,

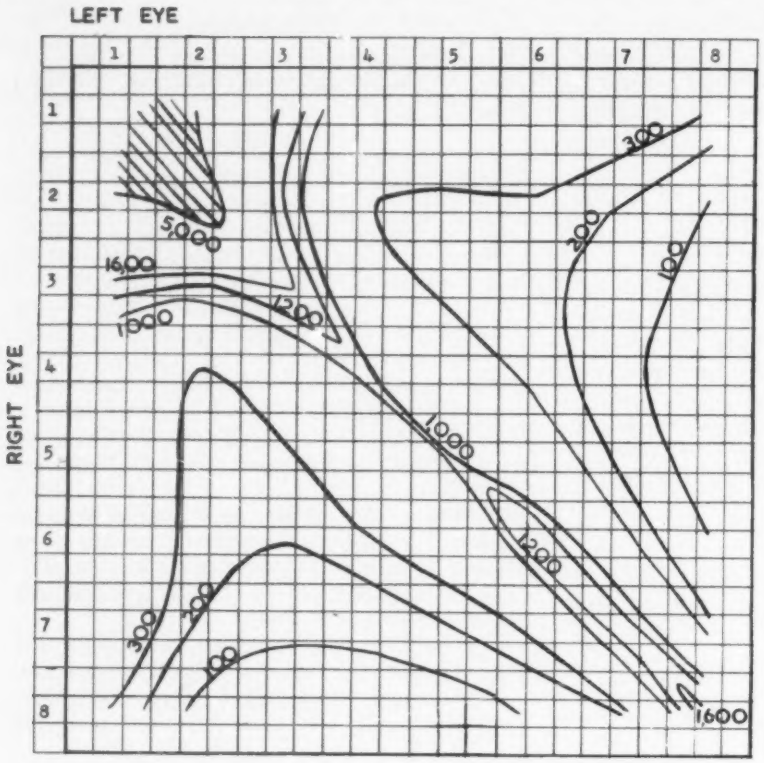

FIG. 1.—Contour diagram illustrating distribution of Army intake for 1952 according to uncorrected vision (*cf.* Table 5).

Thus we are led either to seek an explanation in the routine of examination or lay claim to a fact.

The apparent excess of people with good eyesight whose right eye is slightly weaker than the left might be the result of the right eye always being examined first, so that Snellen's test types have been partially learnt when the left eye comes to be examined. This, however, does not apply to the remainder, for whom the results were as follows:

(*a*) Among those whose uncorrected vision in both eyes was very poor, there were rather more whose left eye was the weaker.

(*b*) Among those with one good eye, whose vision in the other eye was between 6/18 and 6/60, there were more whose left eye was the weaker. The result (*b*) also holds good for corrected vision.

When discharges are related to intake it is found that the lowest rate (9·5 per 1,000 as against the average of 11·5 per 1,000) is for those whose uncorrected vision is (1 1). In general, the discharge rate increases as the uncorrected vision falls. The same result holds for corrected vision.

H: Hearing

This quality also records the result of an objective test. The scale is as follows:

1.	Very good	Forced whisper heard at 20 feet
2.	Good	Forced whisper heard at 10 feet
3.	Moderate defect	Conversational speech heard at 10 ft., with each ear
7.	Marked defect	As *H*3, with both ears
8.	Considerable deafness	

Diseases of the ear are assessed under the quality *P*. Only hearing ability is considered here.

It was observed above (Table 4) that discharges among those with the keenest hearing are greater than among the majority group whose hearing is classed as 2, the other qualities being ignored in the calculation. In order to ascertain whether the same result holds at each level of those qualities, groups were selected whose *U* and *L* qualities were 2, and in which *P* and *M* were 2 or 3, and *S* was 2, 3, or 7. The discharge rates per 1,000 intake in these groups were as follows:—

Degree	*H*1	*H*2
P M S		
2 2 2	1·3	1·3
2 2 3	275·0	159·5
2 2 7	916·7	820·3
3 2 2	5·0	7·3
2 3 2	145·5	31·2

Because of the small numbers involved, the only comparisons of significance are for *S*3 and *M*3. It is

concluded that men of very good hearing are more likely to be discharged when there is also an element of below-average stability or dullness. This is not to say that these conditions are necessarily associated in the population at large. Indeed there are fewer in proportion among those designated *M*3 of those with the acutest hearing.

A systematic study of these associations has been carried out by tabulating the expected numbers for each combination of pairs of qualities and noting the differences from those observed, based on a standard error of the square root of the expected number. This study reveals that poor hearing is associated with stability below the average, while acute hearing is associated with more extreme instability. Poor hearing is also associated with a below-average mentality but acute hearing is not—indeed, the contrary is very marked. But, as already noted, there are more discharges in the group that has this combination than among the *H*1*M*2 group.

The association is marked between poor hearing and a low *P* assessment, partly because climatic restrictions are made on the *P* quality and because a defect of hearing due to disease is classified under both qualities.

M and S: Mental Capacity and Emotional Stability

M is judged on record and on clinical impression, and is an assessment of suitability rather than of intelligence as judged by mental tests. In effect there were only two categories serving, since *M*7 were all discharged; these were the Grade I, *M*2, and the Grade III, *M*3.

S is more complex, since it is sometimes connected with other qualities, and may even be detected only through them. *S*3 counts as Grade II, but it is not acceptable in regular recruits. *S* is the only quality other than *P* that uses degree 6, but not 5, since this quality denotes that a recruit is not suited for service in any climate nor is he fitted to be a combatant.

The *M* and *S* scales are interdependent to some extent, since the policy is to grade the dullard as *S*8 if he is unstable as he is of no use for military service; therefore the combination of *M*3 and *S*3 is seldom used. The associations with *H* are referred to in the previous section on hearing.

There is an association of lower grade mentality with lack of dexterity of the upper limbs and another with a restricted physical grading: there is no administrative instruction to account for this. Also an under-representation of *P*5 and *P*6 indicates that climatic restrictions are not commonly awarded to the duller men, and seems to suggest that disabilities can be divided into two groups, one of which causes the positive association above, while the other is the reverse and is a group sensitive to tropical climates.

The association of instability with below-average *P* is strong, since the psychosomatic disorders impinge on both.

P, U, and L: Physique, Upper and Lower Limbs

The associations of these qualities with hearing, mental capacity, and emotional stability have already been discussed.

U stands for the upper limbs and their operation, which may be governed by a condition affecting *P* also; similarly with *L*. In the latter case, a defect such as flattened arches will only affect the grading if the function is impaired. There are no negative associations in these categories, and *P* naturally tends to be affected by *U* and *L*, as in the practice of awarding *P*8 with *U*8 and *L*8. Associations which involve *P*6 indicate a restriction to temperate climates, as, for example, in subjects with hyperhidrosis. The qualities *U* and *L* do not in themselves register a climatic restriction. Their distribution in the remainder of the scale is dissimilar; in fact a much greater use is made of the lower categories for *L* than for *U*.

As an illustration of the association between qualities it may be noted that 1,085 recruits out of a total of 166,122 had a markedly diminished locomotor efficiency and were graded *L*7. But there were no fewer than 916 of these *L*7s among the 14,377 who were graded *P*3.

The last of the associations to consider is that between *U* and *L*. This association is based on the large number of *P*3s who are both *U*3 and *L*3; this means that *P*3 is almost invariably awarded when the combination of *U*3 and *L*3 occurs, and suggests a common constitutional origin.

The quality *P* may be considered separately. In Table 6 the term "combined" denotes association with a degree of 3 or lower in another quality.

TABLE 6

NUMBERS IN *P* CATEGORIES IN ARMY INTAKE FOR 1952

P Category	Alone	Combined
2	136,397	10,429
3	9,843	4,534
5	2,484	452
6	1,012	364
7	144	137
8	187	139
	150,067	16,055

Among those with a below-average physique, for every combined classification, such as *P*3*L*3, there are rather more than two where *P* is low on its own. About a quarter of those are so graded for conditions where a service in a temperate climate is

recommended, for example, in certain skin diseases and otitis media. Some respiratory diseases also affect grading in this way, when not sufficiently severe to justify a *P*7 or 8. Height and weight are judged within wide limits for natural variation. The height and weight of Army recruits, the measurement of which is part of the PULHEEMS examination, have been analysed elsewhere (Rosenbaum, 1954).

Summary

The initials of the word PULHEEMS stand for the physical and mental qualities which are judged in medical examinations of recruits to the armed Forces. A numerical grading is used for each letter, and this paper analyses the results of examinations of the whole of the 1952 Army intake. Although numerous combinations of grading are possible, the great majority fell into 14 groups. These are not much more complex than the four grades used by the Ministry of Labour and National Service to describe his medical condition to the recruit himself and are far more revealing of causes.

Correlations were found between various qualities: in particular, the quality *P* was strongly associated with other qualities, sometimes on account of a constitutional ailment that had a local effect. Psychosomatic disorders accounted to some extent for the association of emotional instability with physical defects. Associations were found between mental capacity and the physical qualities.

There were also associations of hearing with emotional instability and low mentality, both in those of poor hearing and of extremely acute hearing.

REFERENCE

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THE EFFICIENCY OF VARIOUS LIQUID IMPINGER SAMPLERS IN BACTERIAL AEROSOLS

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The liquid impinger was first described by Greenburg and Smith (1922) as a dust cloud sampler. More recently the device has come into wide use for bacterial aerosol sampling, as it is often very convenient for this purpose both in laboratory apparatus and in the field. Rosebury (1947) and Henderson (1952) describe the use of the "Porton" development of the original device. For estimating the number of viable organisms trapped in the impinger fluid they use the technique of Miles and Misra (1938) in which serial dilutions of the fluid are plated out for subsequent incubation and colony counting.

Valuable features of the impinger when sampling airborne organisms are: (1) It is compact and inexpensive. (2) The sample fluid can be plated out simultaneously on differing media thus ensuring optimum growth conditions for organisms of interest. (3) An extreme range of airborne concentration can be accommodated by the serial dilution technique. (4) Virus aerosols can be estimated effectively, provided that they do not contain a high proportion of very small, single virus particles which are difficult to impinge. (5) The particle retention efficiency is very high, effectively all particles down to about 0·5μ being trapped in the impinger fluid. (6) It gives a measure of the number of individual viable organisms in an aerosol, not the number of infective particles or clusters of organisms. (7) It acts as its own constant-flow metering device. (8) It is unaffected by repeated autoclaving.

Impingers similar to that shown in Fig. 1 were originally developed by Prof. J. H. Gaddum and have been in use in this establishment for many years. Fig. 1 shows the modern all-glass Porton type. Suction is applied to the small side arm and draws air in through the curving intake tube and down through the impinging jet. The jet is a short length of capillary tubing and acts as a critical flow orifice, *i.e.*, when the suction reaches about half an atmosphere the flow in the jet attains sonic velocity (Druett, 1955) and any subsequent increase in suction cannot increase the jet velocity further. Provided therefore that there is at least half an atmosphere of suction the impinger operates at constant flow and, once calibrated, does not require a flowmeter. The sonic velocity air jet strikes the flat base of the flask, throwing out its burden of particles which become suspended in the violently agitated circulating liquid. The apparatus shown in Fig. 1 has a jet diameter of 1·1 mm. giving a flow rate of 11 litres/min. and it holds 10 ml. of liquid in the flask, which has an internal diameter of 1¼ inches. The flask is made long in proportion to its width so that splashes of liquid cannot be entrained out of the suction tube (Rosebury used a conical flask which splashes less owing to the broader base, and which stands safely on the bench). The distance between the jet and flask base is 4 mm.

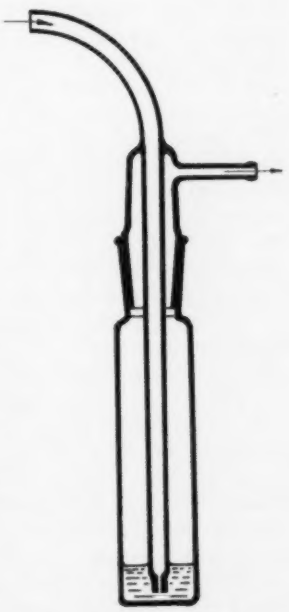

FIG. 1.—All-glass Porton impinger.

It will readily be seen that the impingement process is of great violence, for in a distance of about 1 cm. particles are accelerated up to sonic speed (about 760 m.p.h.) and are thrown against the hard glass base of the flask at approxi-

mately this speed. While this is known to shatter aggregated dust particles, experiments here with heat-resistant bacterial spores of *B. subtilis* had shown that their viability was in no way affected by the impingement process and it was assumed that this was so with more delicate vegetative cells. Doubt was thrown on this point by the advent of the American "Shipe" impinger (U.S. Chemical Corps, 1953) which in both countries was found to give consistently higher viable recoveries from various airborne vegetative cells than our Porton type of impinger. The Shipe impinger (Fig. 2A) has a critical orifice plate cemented into a side neck close to the base of the flask. The neck and air jet are inclined downwards and in the plan view are tangential to the side of the flask as shown. The air jet therefore strikes the base of the flask at a glancing angle and also imparts a very vigorous, non-splashing rotation to the impinger fluid. On the top of the Shipe flask fits a standard ground glass joint, with the suction tube blown into the upper portion.

There are three important differences between the Shipe and Porton impingers which might affect the viable recovery, as follows:—

(1) Intake Differences.—The particle-laden air stream reaches the impinging jet via a long curving tube in the Porton impinger whereas access to the Shipe jet is direct from the air. The curving tube traps by inertial effects the more massive airborne particles. This selective filtration was originally intended by Gaddum to simulate the human nose, though we now know that the existing tube is much less efficient than the nose. The standard suction rate of 11 litres/min. through the 8 mm. internal diameter intake tube of the Porton impinger gives a 50% retention in the bend of unit density particles of about 12μ diameter (the corresponding figure for the nasal system is about 4μ) while particles larger than about 18μ are entirely prevented from reaching the impinging jet. Hence the Shipe impinger will always show a higher recovery from aerosols containing large particles, the effect being emphasized by the number of organisms contained in a cluster being proportional to the cube of its diameter. An entirely separate effect is that the " intake efficiency", or ability of the larger particles to enter the Porton tube or the Shipe orifice, may be markedly different in the two impingers in cross draughts or winds, due to differences in the inflowing air streamlines. Clearly, any experiment designed to measure differences between these two, or any other impinging systems in respect of killing effects on viable particles, must be confined (*a*) to the use of particles small enough to be unaffected by tube losses or intake efficiency differences, or (*b*) to impingers with identical intake systems, or (*c*) to impingers fitted with a device such as the " pre-impinger " (May and Druett, 1953), which only permits particles of a small and known size to reach the backing impinger.

(2) Jet Differences.—The Porton impinger jet is formed from a short length of glass capillary whereas the Shipe jet is a hole drilled in a thin plate. The Porton jet, which is illustrated in Fig. 2B, can be criticized on two counts: (*a*) The transition from the 8 mm. intake tube to the 1 mm. jet is too abrupt, as shown by the fact that if the sample contains particles larger than about 3μ an appreciable deposition may be observed on the lead-in to the jet, even with a pre-impinger in use, and (*b*) there is no need for the jet to have any parallel portion at all for it to form a critical orifice. Davies, Aylward, and Leacey (1951) consider that a long, narrow, parallel-sided jet will, by shearing forces, break up particles of coal dust and it is possible that the shear forces in the capillary may in some cases have a bad effect on the viability of the more delicate organisms. Break up of cell clusters into their components is not in itself undesirable since the method of assay depends on each counted colony stemming from a single cell. Probably then the best shape for the Porton jet would be similar to that shown in Fig. 2C but leading down to a smaller hole with a very short parallel portion. The Porton jet was originally made in the Fig. 2B form because suitable capillary tubing can be readily obtained and quickly fused on the glass tube to give a standard flow-rate without further adjustment, and also probably because it was felt that a parallel portion was necessary to allow particles time to be accelerated by air drag up to the full jet velocity. The Fig. 2C form would be only slightly more difficult to make, should eliminate lead-in losses and would give satisfactory particle velocities because, as the results of this work will show, the full sonic velocity is not in general necessary to impinge the smallest bacterial particles. We shall, however, show that the Porton jet in its standard form will, with a suitable modification of the jet height, give similar viable recoveries to the Shipe, under the conditions of the tests.

(3) Impingement Velocity Differences.—After eliminating or making allowances for differences (1) and (2) above, the Shipe still showed an advantage in viable recovery. The remaining difference was therefore considered to be of fundamental importance. This is that the distance between the jet orifice and point of impingement (h in Fig. 2B) is 4 mm. for the Porton impinger with the air jet impinging vertically on the flat base and in the Shipe impinger is 30-40 mm. with oblique impingement

on the base. The violence of the impingement process is therefore much less in the Shipe, where the jet has time to lose much of its velocity by turbulent diffusion before striking the base.

In spite of the extreme violence of the impingement process in the Porton impinger, it is difficult to picture how an object with such a small mass as the bacterial cell (less than 10^{-12} g.) could be damaged by it. Conversion of the whole of the kinetic energy of the cell into heat could at the most only raise the temperature of the cell by a few degrees C., but owing to adiabatic cooling of the air jet and evaporative cooling of the impinger fluid in which the cell is immediately immersed, it seems doubtful if any actual temperature rise, however transient, could occur. It was thought that a permanently dry spot might exist in the centre of the impingement area or that cells might adhere firmly to the glass surface of the area and so escape suspension in the impinger fluid. In experiments to test these points these effects did not occur to any appreciable extent. Some form of mechanical trauma to the cell seems to be the only remaining possibility to account for loss of viability but we have been unable to devise any test for this point. A possible clue is that all the cells with which we have observed a killing effect are Gram-negative and these under manipulation are flabbier than Gram-positive cells (E. O. Powell, private communication). We have, however, not worked with Gram-positive cells other than the spores.

In view of the difference in performance of the two impingers we decided to carry out comparative tests of impingers with differing geometrical layouts and varying impingement velocity to see if any one form was superior in (*a*) the viable recovery obtainable from it and (*b*) the ease of modifying the Porton impinger to that form. We wished to retain unchanged the outer glassware of the Porton impinger because of the large stocks in hand together with matching ancillary equipment.

Types of Impingers Tested

The impinging systems tested are shown in Fig. 2. The Shipe impinger A and the standard Porton form B with jet clearance h = 4 mm. have already been described. The remaining types were all built into the standard Porton flask and all operate in the range 10·5-11·5 litres/min.

The " Sub-critical " Impinger, C.—This has subsonic jet velocity with the flow controlled by a critical orifice on the outlet tube of the impinger. For the tests, inlet tubes smoothly tapering down to jets of 2·2, 1·7, and 1·42 mm. were fitted, these being thought fine enough to give high impingement efficiency for 1 μ single cell particles. The clearance h was 4 mm. for each jet.

The " Venturi Jet " Impinger, D.—A jet of the form shown has the characteristic that constant flow starts at a much lower pressure drop than for the simple orifice or parallel-sided jet of Fig. 2A and B. Whereas the latter require at least half an atmosphere of suction for constant flow, the Venturi with the diverging cone at the optimum of 4° included angle requires only one-fifth of an atmosphere. Thus a considerable economy of suction power would be possible with this type of impinger.

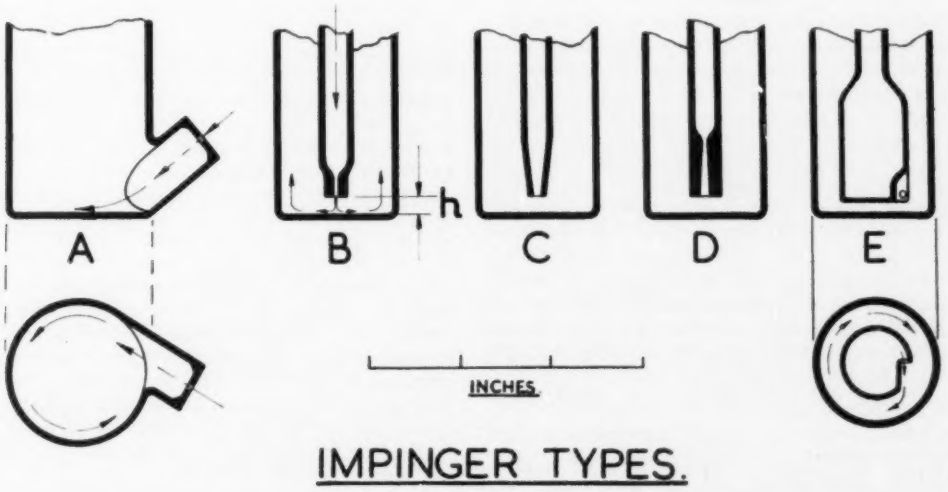

FIG. 2.—Impingement systems tested.

Venturi orifices are discussed by Druett (1955). The air velocity at the end of the expanding cone is, however, a function of the pressure drop, varying from low subsonic for small suction to supersonic when the suction approaches one atmosphere. The impinger would therefore have to operate at a specified pressure drop, otherwise the impingement performance would be expected to vary. The clearance h was 4 mm. The length of the diverging cone was 17 mm. and the lower orifice diameter was 2·3 mm. The throat diameter was 1·1 mm.

The "Swirling" Impinger, E.—This simulated the Shipe in that the impinging jet struck the lower wall of the flask tangentially and swirled the liquid round, but the swirl was more rapid than in the Shipe and the impingement distance shorter. The bottle-shaped end to the central tube seemed to be a suitable way of producing a jet at the required angle by boring through a kink in the wall, though there are of course other ways.

Bead Bubbler.—To confirm that impingement is the best means of sampling single-cell aerosols into liquids a bead-bubbler (not illustrated), as used for gas sampling, was tested. These bubblers comprise a glass tube of about 4 cm. internal diameter and 10 cm. long, half filled with glass beads of about 3 mm. diameter. The sample intake tube leads to the bottom of the bubbler with the outlet tube at the top and the indrawn air bubbles up through liquid filling the interstices of the beads. The 3 mm. beads were the finest that could be effectively used at our standard flow rate of 11 litres/min.

Procedure

(a) General.—Initial screening tests of the impingers described above were done in the single-cell aerosol generated by the Henderson spray apparatus (1952). The bacterial suspension sprayed was a mixture in known ratio of spores of *B. subtilis var. niger* and vegetative cells of *S. marcescens*. The robust *B. subtilis* spore was chosen as it is very suitable for obtaining the "filtration efficiency"* of an impingement system while the *S. marcescens* is delicate and usually gives a low viable recovery in the Porton impinger. Both organisms have the advantage of being non-pathogenic and can be separately cultured from samples of the same sampler fluid. They can readily be prepared as stable, non-clumping suspensions for spraying. By spraying and sampling the mixed suspension one can obtain strictly comparative figures for the filtration and viable recovery efficiencies in the same experiment. If *B. subtilis* spores are held in contact with nutrients from *S. marcescens* suspensions, either in liquid suspension or as an aerosol, they may undergo the first stages of germination, *i.e.*, lose heat resistance. In this state they are much more susceptible to damage in impingement processes. In the present experiments this was avoided by using *S. marcescens* suspensions almost free from nutrients with freshly heated spore suspensions to eliminate any heat-sensitive spores that may have been present and by strictly limiting the time of contact.

The screening tests with the single-cell aerosol having been completed, the type of impinger with most merit was selected and subjected to further comparative tests against the Porton impinger. These comprised tests in the open air in aerosols of coarser heterogeneous particles from the same mixed suspension as before and laboratory tests with pathogenic organisms.

(b) Bacteriological Preparation.—All *S. marcescens* suspensions were freshly prepared from the same strain. The *S. marcescens* was grown on peptone agar containing 1% mannitol, reaped into phosphate buffer, and used within 48 hours. This was done because the viable count of the suspension and its aerosol resistance fell off rapidly after this time. A single batch of *B. subtilis* spores was used throughout the tests. This had been prepared by growing on CCY agar, reaping in water, and heating at 60° C. to kill off vegetative forms. The mixed suspensions sprayed in the Henderson apparatus contained these organisms in approximately equal proportion, with a viable cell count of about 5×10^7 of each per millilitre of suspension. The actual counts were separately assessed before each experiment.

(c) Sampling and Assessment.—All aerosol samples were taken over a period of one minute in the laboratory work and were impinged into 10 ml. of phosphate buffer containing 0·25% "manucol" (sodium alginate). Dilutions were made in the same fluid. The function of the 'manucol" is to counter the effects of the so-called "agitation phenomenon" (Henderson, 1952). This is a progressive loss, which has been observed with spores, during agitation of the impinger fluid by the air jet. It is due to spores clumping together and sticking to the glassware. Manucol has been found to make this effect very small.

For assessment of *S. marcescens*, samples were plated on peptone agar containing 1% mannitol with the addition of 1/400,000 methyl violet to suppress spore growth. The *B. subtilis* was then assessed by heating the dilution tubes in a water-bath at 60° C. to kill the *S. marcescens* before plating on peptone agar.

In assessing any individual sample, colonies on quadruplicate culture plates were counted after suitable incubation. The plates assessed were those where the six uniform drops placed on them from the serial dilutions gave a colony count in the approximate range 100-200. Thus each sample was an estimate obtained from counting usually 400 to 800 colonies and was subject to an inherent standard error of roughly ±5% from the Poissonian distribution of samples of this size.

Each type of sampler was tested against a standard (h = 4 mm.) Porton impinger which took a simultaneous

* "Filtration efficiency" in this work is the ratio of the number of particles found in the sampling device to the total number of particles entering the sampler, the latter being estimated by the number on an efficient backing filter + the sample recovery. It is a purely physical concept.

reference sample from the same port via a Y-tube in the Henderson apparatus. Impingers were interchanged in successive comparisons. The viable recovery from the Porton impinger was taken as an arbitrary standard of unity in computing the relative performance of the other devices.

Notes on the Tabulated Results

(*a*) For convenience in presentation and comparison, the ratio of the number of viable cells of *B. subtilis* to the number of viable vegetative cells in the sprayed suspension, as estimated before each experiment, was numerically adjusted to unity. The same adjusting factor was then applied to the ratio found in the samples so that a direct comparison can be made between different tables.

(*b*) An " experiment " embraces work done in a single day with one setting of the spray apparatus and the same suspension throughout.

The difference which will be observed in aerosol concentration from experiment to experiment is mostly due to variations in the suspension mixtures made up before each.

A single " comparison " is derived from the two single, simultaneous samples taken by the Porton and test impingers. It was not possible always to make the same number of comparisons in each experiment owing to the considerable effort involved in the assessments and the pressure of other work.

(*c*) All " aerosol concentration " figures are the means of the estimations from the individual samples in the stated number of comparisons. They are expressed as viable cells ($\times 10^{-4}$) per litre of air drawn through the sampler. It is convenient to present the relative recoveries from different impingers in this way as their sampling flow rates usually differ a little.

The " ratios " are the means from the stated number of comparisons.

(*d*) To illustrate the reproducibility to be expected in this type of work, which involves several sources of error, standard deviations, $\sqrt{\Sigma (x - \bar{x})^2 / (n - 1)}$, are given with those aerosol concentrations or ratios which are of particular interest. Each standard deviation is derived from the spread of the values from each experiment, n being the number of comparisons shown in col. 2 in all tables except Table 9. The mean figures at the foot of the tables were obtained by giving equal weight to all individual comparisons summarized in the table.

Where only a small number of samples was involved or where the performance of the sampler under test was clearly poor, the standard deviations are not presented.

The average coefficient of variation from all experiments was 10·1%.

(*e*) In the last column of all tables except Tables 1 and 9 is given the ratio of the viable vegetative cell recovery from the test impinger to the viable *B. subtilis* recovery in the Porton impinger. We know that the loss of *B. subtilis* between spraying and assessment from the Porton impinger is very small (see below). In Tables 2, 3, 4(*c*), and 6 where we have efficient test impingers the ratio in the last column is close to unity and we can therefore make the important inference that no *S. marcescens* was killed in spraying or sampling. The tendency for the ratio to be rather greater than unity in Tables 2 and 3 will be discussed later. Where the ratio is significantly less than unity it indicates quantitatively the loss of *S. marcescens* due to the sampling process alone as, apart from the different test impingers, all experiments were carried out in an identical manner. The ratio can, however, only be taken as a measure of the " kill " of *S. marcescens* where the impingement velocity was high enough to give close to 100% filtration efficiency for the two different sizes of single cell particle, *S. marcescens* being smaller than *B. subtilis*. When the impingement velocity was low and the *S. marcescens*/*B. subtilis* ratio also low, this may be due to lower filtration efficiency for *S. marcescens* rather than loss of viability (an extreme case of this is seen in the bead-bubbler results, Table 7). The determination of filtration efficiencies for sensitive vegetative cells is very difficult and was not attempted.

Results with the Porton Impinger

***B. subtilis* Recovery.**—The basis of the tests was that the Porton impinger gives virtually 100% filtration and viable recovery efficiency with *B. subtilis* spores. This has been established by workers here and in America (Henderson, 1952; Rosebury, 1947), but a re-check was made at the start of the present series of tests. This was done by finding the number of viable *B. subtilis* cells recovered from the impinger and from a resin-wool filter sampling in parallel. The latter material is used in respirators, has an extremely high particle retention efficiency, and spores can readily be assessed from it by shaking with glass beads in buffer for subsequent plating out.

The results from six comparisons were: Aerosol concentration estimated by Porton impinger 5·33 ($\pm$0·34), by filter 5·32 ($\pm$0·23). These figures confirm the suitability of the Porton impinger as a standard for comparison. Further consolidation of this point has been obtained by experiments here with radioactively tagged cells. These experiments gave counts of cell material independent of viability by the purely physical Geiger count and showed that there was no loss of viability in filters or impingers when freshly heated spores had been used to produce single cell aerosols.

***S. marcescens* Recovery.**—The ratio of viable *S. marcescens*/*B. subtilis* recovered from the standard 1 : 1 mixed suspension (see Note (*a*) above) from nine experiments which gave 61 comparisons was $0{\cdot}76 \pm 0{\cdot}034$. This indicates a loss of 24% of *S. marcescens* on sampling (Note (*e*)).

Effect of Modifications.—An obvious and very simple modification is to increase the distance h (Fig. 2) and allow the air jet time to lose velocity by turbulent diffusion before it strikes the base. This is permissible as the impingement velocity in the h = 4 mm. impinger is higher than it need be to trap all single cells, but we would expect a continuous fall in filtration efficiency as h is increased beyond a certain value.

To study the effect of increasing h, impingers with h = 18, 25, 30, 34, 40, 45, 50, 55, 60, 69, and 105 mm. were tested for single *B. subtilis* cell filtration efficiency and for viable *S. marcescens* recovery. All were filled with 10 ml. of collecting fluid. The results obtained are plotted in Fig. 3. The numbers by each plotted point are the numbers of comparisons made in obtaining that point. The upper curve of relative *S. marcescens* recovery shows a steady increase in recovery to a maximum of 134% as the distance h is increased to the optimum of 30 to 35 mm. At this distance the filtration efficiency as shown by the lower curve is only slightly lower than at h = 4 mm. Further increase in h gives the expected continuous fall in filtration efficiency which is reflected by the fall in the upper curve.

It was thought possible that the impinger with its jet raised to the optimum height of 30 mm. might show some variation in performance with pressure drop because of changes in expanding jet velocity or changes in splashing characteristics. To check this point a few tests were made and the results are presented in Table 1. Although a small change in filtration efficiency is indicated, there is no marked effect on the viable recovery figures even when the suction is only 8 in. of mercury, which is well below the critical flow value of 15 in. The low *B. subtilis* ratio in col. 9 at 15 in. Hg is thought to be experimental error, Table 2 giving more accurate figures for suction at this level.

Table 2 summarizes all the comparisons made at what Fig. 3 shows to be the optimum h value for this type of impinger. Column 8 shows that the modified form gave an *S. marcescens* recovery 34% greater than the Porton form. The values in col. 9 indicate that all the airborne *S. marcescens* was recovered in viable form from the modified impinger (see Note (*e*) above). Fourteen of the 20 comparisons summarized in col. 9 gave *S. marcescens*/*B. subtilis* ratios exceeding unity, however. This is statistically significant and implies that there was some small loss of *B. subtilis* in the Porton impinger, perhaps by "agitation" effects in spite of the "manucol",

TABLE 1

IMPINGER (h = 30 mm.) WORKING AT VARIOUS SUCTION LEVELS COMPARED WITH PORTON IMPINGER AT CONSTANT SUCTION

Negative Pressure on h = 30mm. Impinger (In. Hg.)	No. of Comparisons	% Filtration Efficiency		Aerosol Concentration of				Ratio (%) = 30 mm. h / Porton for	
				B. subtilis from		*S. marcescens* from			
		Porton Impinger	h = 30 mm. Impinger	Porton Impinger	h = 30mm. Impinger	Porton Impinger	h = 30mm. Impinger	*B. subtilis*	*S. marcescens*
8	2	99·9	94·0	10·06	9·77	7·96	10·00	97	126
15	2	99·9	97·5	9·61	9·06	6·84	9·00	94	132
27	2	99·9	99·7	8·96	8·65	5·99	7·81	97	130

TABLE 2

IMPINGER (h = 30 mm.) TESTED AGAINST PORTON IMPINGER

Experiment No.	No. of Comparisons	Aerosol Concentration of				Ratio (%) of Test/Porton Impingers for		Ratio (%) of *S. marcescens* from Test Impinger / *B. subtilis* from Porton Impinger (Col. 6/3)
		B. subtilis from		*S. marcescens* from				
		Porton Impinger	Test Impinger	Porton Impinger	Test Impinger	*B. subtilis* (Col. 4/3)	*S. marcescens* (Col. 6/5)	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	6	$8{\cdot}53 \pm 0{\cdot}45$	$8{\cdot}27 \pm 0{\cdot}56$	$6{\cdot}90 \pm 0{\cdot}94$	$8{\cdot}78 \pm 1{\cdot}55$	98 ± 11	129 ± 34	105 ± 21
2	6	$5{\cdot}27 \pm 0{\cdot}26$	$5{\cdot}42 \pm 0{\cdot}33$	$4{\cdot}49 \pm 0{\cdot}38$	$5{\cdot}89 \pm 0{\cdot}34$	103 ± 5	132 ± 6	112 ± 4
3	2	9·45	9·03	6·32	9·00	96	142	95
4	2	9·36	9·31	7·31	9·21	99	126	98
5	2	7·45	7·39	6·00	9·05	99	151	121
6	2	6·32	5·75	5·23	7·38	91	141	116
Means of	20	—	—	—	—	99 ± 8	134 ± 19	108 ± 14

Filtration efficiency of h = 30 mm. impinger = $97{\cdot}4\% \pm 0{\cdot}6$ (8 tests).
Entries are, Sample mean $\pm$ estimated population standard deviation.

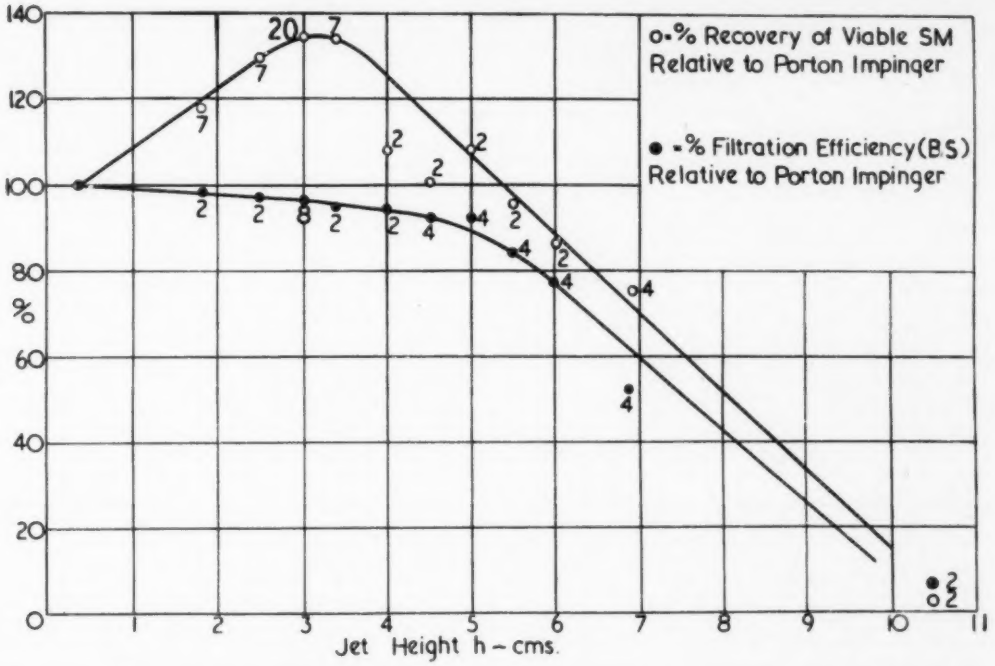

FIG. 3.—Effect of varying impingement distance in Porton impinger. The numerals by each plotted point give the number of tests made in establishing that point. BS = *B. subtilis*; SM = *S. marcescens*.

though this is contrary to the filtration efficiency results.

Results with the Shipe Impinger

Comparison of the means at the foot of Table 3 with those of Table 2 shows that the two types of impinger concerned gave effectively identical results. Their filtration efficiencies are also closely similar. The filtration efficiency and *S. marcescens* recovery figures relative to the Porton impinger also agree very well with those reported by American workers (U.S. Chemical Corps, 1953).

The figures in col. 9 are again very difficult to account for. Statistically the overall mean of 113% is significantly greater than unity as 12 out of the 15 comparisons yielded figures above unity.

Results with the Sub-critical Impinger

Of the three jet sizes tested it is clear from Table 4 that the two larger ones (*a*) and (*b*) do not compare with the Shipe or h = 30 mm. impingers in *S. marcescens* recovery (col. 8). This is because the relatively low jet velocity gives a low impingement efficiency.

The 1·42 mm. jet(*c*), however, gives a performance which is not significantly different from the mean

TABLE 3

SHIPE IMPINGER TESTED AGAINST PORTON IMPINGER

Experiment No.	No. of Comparisons	Aerosol Concentration of *B. subtilis* from Porton Impinger	Aerosol Concentration of *B. subtilis* from Test Impinger	Aerosol Concentration of *S. marcescens* from Porton Impinger	Aerosol Concentration of *S. marcescens* from Test Impinger	Ratio (%) of Test/Porton Impingers for *B. subtilis* (Col. 4/3)	Ratio (%) of Test/Porton Impingers for *S. marcescens* (Col. 6/5)	Ratio (%) of *S. marcescens* from Test Impinger / *B. subtilis* from Porton Impinger (Col. 6/3)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	6	6·27 ± 0·31	6·27 ± 0·17	5·35 ± 0·46	7·26 ± 0·53	100 ± 5	136 ± 13	116
2	2	8·43	7·37	6·98	8·00	87	115	95
3	3	8·17	8·55	7·67	10·03	105	131	123
4	2	9·02	8·16	7·12	10·11	91	142	112
5	2	7·45	7·04	6·03	8·08	94	134	109
Means of 15	—	—	—	—	—	97 ± 7	133 ± 15	113 ± 11

Filtration efficiency of Shipe impinger = 98·2% ± 0·8 (8 tests).

TABLE 4

SUB-CRITICAL IMPINGERS TESTED AGAINST PORTON IMPINGER

Experiment No. (1)	No. of Comparisons (2)	Aerosol Concentration of *B. subtilis* from Porton Impinger (3)	Aerosol Concentration of *B. subtilis* from Test Impinger (4)	Aerosol Concentration of *S. marcescens* from Porton Impinger (5)	Aerosol Concentration of *S. marcescens* from Test Impinger (6)	Ratio (%) of Test/Porton Impingers for *B. subtilis* (Col. 4/3) (7)	Ratio (%) of Test/Porton Impingers for *S. marcescens* (Col. 6/5) (8)	Ratio (%) of *S. marcescens* from Test Impinger / *B. subtilis* from Porton Impinger (Col. 6/3) (9)
(*a*)								
1	3	5·25	4·13	4·17	3·02	79	72	59
2	3	6·19	4·72	5·22	4·37	76	84	71
Means of 6						78	79	65
(*b*)								
1	3	5·07	5·29	3·84	4·33	104	113	86
2	3	6·20	5·50	5·82	5·82	89	100	94
3	3	5·39	5·25	4·44	4·69	96	106	87
4	3	6·18	5·48	5·58	5·71	89	102	93
Means of 12						96 ± 16	106 ± 15	90 ± 17
(*c*)								
1	4	8·93	9·09	6·99	9·00	102	130	101
2	4	10·86	11·43	8·53	11·01	103	129	101
Means of 8						103 ± 8	130 ± 14	101 ± 9

(*a*) Sub-critical jet 2·2 mm. dia. Filtration efficiency 72·5% ± 5·1 (6 tests) at 11 l/min.
(*b*) Sub-critical jet 1·7 mm. dia. Filtration efficiency 96·6% ± 0·7 (12 tests) at 11 l/min.
(*c*) Sub-critical jet 1·42 mm. dia. Filtration efficiency 99·80% ± 0·02 (4 tests) at 11 l/min.

figures of Table 2 and 3, cols. 7 and 8. The filtration efficiency is also very good. The velocity in the jet and 4 mm. below it at the point of impingement when running at 11 litres/min. would be a little below 300 m.p.h. which is similar to a value measured at the impingement point in the h = 30 mm. impinger. The pressure drop across the sub-critical jet at this flow rate is only about 1·2 in. Hg. The effect of the relatively low velocity and pressure drop as compared with the critical-flow impingers is that splashing, liquid loss through evaporation, and evaporative cooling are greatly reduced. In a critical flow impinger evaporation losses can become serious in sampling periods longer than one minute, especially at high temperatures and low humidities, and the liquid can freeze at low humidities and temperatures.

According to the work of Rang and Wong (1952) on circular impinging jets, the velocity given by this 1·42 mm. diam. jet at 11 litres/min. running dry is slightly greater than that required to give 100% impingement efficiency for 1 micron unit density spheres, and this jet was in fact chosen for that reason. The filtration efficiency figure, 99·8% for the single *B. subtilis* spores, is therefore as was hoped for this jet, without allowing for the enhancement of retention which the presence of the impinger fluid should give. The small quantity of spores which always penetrate through the impinger even with the most efficient jet are probably carried through by minute droplets originating in the violent splashing of the impinger fluid.

The filtration efficiency figures for the 1·7 mm. and 2·2 mm. sub-critical jets (96·6% and 72·5%) are higher than Rang and Wong's figures (90% and 25%) would suggest, but this can be attributed to the presence of the impinger fluid.

The mean value of col. 9 in Table 4(*c*) indicates complete recovery of all sprayed *S. marcescens* and there is no anomaly suggesting some *B. subtilis* loss as in Tables 2 and 3.

Results with the Venturi Jet Impinger

The performance of this type of jet at three suction levels, namely 6 in. Hg (the minimum suction for critical flow in this type of jet), 15 in. Hg, and 25 in. Hg, is shown in sections *a*, *b*, and *c* of Table 5. Col. 8 indicates that there is some improvement over the Porton type in *S. marcescens* recovery at the two lower suction levels, where the impingement velocities would be relatively low, but the diameter at the bottom of the nozzle, which is one of the parameters determining impingement efficiency, is in this case apparently too great for the efficiency to be very high at the velocity obtaining. The col. 9 figures are low because of the low filtration efficiency (c.f. Note (*e*) above). At the high suction level (Table 5(*c*)) the impingement velocity is probably in the supersonic region though this is not amenable to reliable calculation. The filtration efficiency is now very good but the *S. marcescens* recovery relative to the Porton impinger (col. 8) has dropped to a very low level which can only be due to the high impingement velocity. Col. 9 indicates that about half of the *S. marcescens* is " killed " at this high suction and velocity level.

TABLE 5

VENTURI JET IMPINGER TESTED AGAINST PORTON IMPINGER

Experiment No. (1)	No. of Comparisons (2)	Aerosol Concentration of *B. subtilis* from Porton Impinger (3)	Aerosol Concentration of *B. subtilis* from Test Impinger (4)	Aerosol Concentration of *S. marcescens* from Porton Impinger (5)	Aerosol Concentration of *S. marcescens* from Test Impinger (6)	Ratio (%) of Test/Porton Impingers for *B. subtilis* (Col. 4/3) (7)	Ratio (%) of Test/Porton Impingers for *S. marcescens* (Col. 6/5) (8)	Ratio (%) of *S. marcescens* from Test Impinger / *B. subtilis* from Porton Impinger (Col. 6/3) (9)
(*a*) 1	10	8·82	8·05	6·70	7·25	91	108	82
(*b*) 1	10	8·93	8·37	6·83	8·12	94	119	91
(*c*) 1	3	7·06	6·94	6·05	4·65	98	77	66
2	4	6·50	5·85	5·65	3·55	90	63	55
3	4	8·64	8·24	6·71	3·60	95	54	42
Means of 11						94	64	54

(*a*) Venturi jet operating at 6 in. Hg pressure drop. Filtration efficiency 92·5% (7 tests).
(*b*) Venturi jet operating at 15 in. Hg pressure drop. Filtration efficiency 98·5% (7 tests).
(*c*) Venturi jet operating at 25 in. Hg pressure drop. Filtration efficiency 99·57% ± 0·11 (3 tests) (11·6 l/min.)

Table 5 shows clearly how the performance of this type of impinger varies markedly with the applied suction.

Results with the Swirling Impinger

The mean figures of Table 6 show a marked improvement over the Porton impinger, though not so great as in Tables 2, 3, and 4. When running, this impinger gives a very vigorous swirl with little splashing.

Results with the Bead Bubbler

The figures in Table 7 show that in spite of the thick bed of fine beads through which the sampled air bubbles, filtration efficiency with these small particles is low. No killing effect on the vegetative cells is indicated and for coarser aerosols the method would probably be entirely effective.

Review of Above Work

The tables show that the Shipe, h = 30 mm., and sub-critical (*c*) impingers give performance figures of high and equal merit. The Venturi jet and swirling types were inferior for reasons given above, and, although swirling types could no doubt be developed to give a very good performance, they would always be more difficult to make than the h = 30 mm. and sub-critical types.

The simplest modification of our existing large stocks was clearly to raise the jet of the Porton impinger to 30 mm. by shortening the inlet tube, although fundamentally the sub-critical type is

TABLE 6

SWIRLING IMPINGER TESTED AGAINST PORTON IMPINGER

Experiment No. (1)	No. of Comparisons (2)	Aerosol Concentration of *B. subtilis* from Porton Impinger (3)	Aerosol Concentration of *B. subtilis* from Test Impinger (4)	Aerosol Concentration of *S. marcescens* from Porton Impinger (5)	Aerosol Concentration of *S. marcescens* from Test Impinger (6)	Ratio (%) of Test/Porton Impingers for *B. subtilis* (Col. 4/3) (7)	Ratio (%) of Test/Porton Impingers for *S. marcescens* (Col. 6/5) (8)	Ratio (%) of *S. marcescens* from Test Impinger / *B. subtilis* from Porton Impinger (Col. 6/3) (9)
1	1	9·61	10·49	6·49	9·52	109	147	99
2	2	8·29	8·40	6·78	10·10	101	149	120
3	2	7·45	6·90	6·03	7·53	93	125	101
4	3	7·13	6·93	5·54	6·76	95	122	95
5	3	8·19	8·21	6·80	7·00	100	103	85
6	3	6·80	6·54	5·63	6·68	96	119	98
Means of	14					99 ± 8	124 ± 18	99 ± 13

Filtration efficiency 99·6% (3 tests).

TABLE 7

BEAD BUBBLER TESTED AGAINST PORTON IMPINGER

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	1	8·92	4·54	7·00	4·45	51	64	50

Filtration efficiency 67·2% (1 test).

TABLE 8

RAISED (h = 30 mm.) IMPINGER COMPARED WITH PORTON IMPINGER FOR THE RECOVERY OF VARIOUS VEGETATIVE ORGANISMS

Organism	No. of Comparisons	Aerosol Concentration of *B. subtilis* from		Aerosol Concentration of Vegetative Organism from		Recovery Ratio (%) of Raised/Porton Impingers for		Ratio (%) of Vegetative Organism from Raised Impinger / *B. subtilis* from Porton Impinger
		Porton	Raised	Porton	Raised	*B. subtilis*	Vegetative Organism	
S. marcescens	20	data from Table 2				99 ± 8	134 ± 19	108 ± 14
P. tularensis	6	4·50	4·19	0·51	0·67	94 ± 14	132 ± 11	16 ± 3
P. pestis	6	5·50	5·29	5·39	5·40	96 ± 6	100 ± 9	98 ± 6
B. suis	6	4·59	4·35	4·73	4·76	96 ± 9	101 ± 7	104 ± 13

perhaps more attractive with its constant small pressure drop, smaller liquid evaporation and cooling, reduced chance of jet blockage and with its smooth lead-in to the jet.

The decision was taken to concentrate on the h = 30 mm. type and it was then designated the " raised " impinger.

Further Tests on Raised Impinger

Table 8 shows results obtained with additional vegetative organisms in the Henderson single-cell aerosol apparatus. With *P. tularensis* the " raised " impinger shows an improvement over the Porton type similar to that for *S. marcescens* (col. 8). Col. 9 shows that the actual recovery of *P. tularensis* was only a small fraction of that sprayed but we had reason to believe that most of the loss took place during the spraying and drying of this extremely delicate organism.

With *P. pestis* and *Br. suis* the " raised " impinger gave the same high recovery as the Porton type but these organisms are known to be very robust in the conditions of the Henderson apparatus and there was no reason to expect loss of viability in the Porton impinger.

Open-air Work

To simulate naturally occurring aerosols more closely than did the laboratory work, tests were carried out over open ground using a small compressed air atomizer to produce an aerosol of heterogeneous particle size. The suspensions sprayed were of mixed *B. subtilis* and *S. marcescens*, similar to those used in the laboratory tests, except that 2% of glycerol was added in an attempt to protect the *S.marcescens* from death when the sprayed droplets dried down to equilibrium with the atmospheric humidity.

Sampling was carried out by small groups of impingers. Raised and Porton types were in close pairs so that as far as possible the two types received the same dose of aerosol. Each impinger was fitted with a pre-impinger (May and Druett, 1953) which allowed only the respirable fraction ($< 5\mu$) of the sprayed aerosol particles to reach the impinger. The groups of impingers were placed down wind at distances which roughly depended on the prevailing wind speed, the object being to allow the droplets time to dry to equilibrium with the atmosphere. Air temperatures were in the 40°-55° F. range and humidities usually exceeded 80% R.H.

Results of the tests are summarized in Table 9. The reason for the great variability in total cell recovery from test to test is partly due to the variable distance down wind and partly to the chance as to whether or not the small group of impingers happened to stand in the region of peak concentration of the diffusing swathe of aerosol proceeding down wind from the spray. The striking feature of this series of tests is that the recovery ratios in the last

TABLE 9

RAISED IMPINGERS TESTED AGAINST PORTON IMPINGERS FOR RECOVERY OF *B. subtilis* AND *S. marcescens* FROM HETEROGENEOUS SPRAY IN OPEN AIR

Test No.	Total Cells in Pools ($\times 10^{-4}$) of *B. subtilis*		Total Cells in Pools ($\times 10^{-4}$) of *S. marcescens*		Ratio (%) of Raised/Porton for	
	Porton	Raised	Porton	Raised	*B. subtilis*	*S. marcescens*
1	640	765	247	828	120	335
2	960	1225	394	1100	128	279
3	28·4	48·0	14·0	44·7	169	319
4	39·6	56·4	23·0	67·5	143	293
5	55·5	57·8	29·3	75·4	104	258
6	58·5	53·8	17·6	24·8	92	141
7	64·0	61·6	42·9	65·4	96	153
8	58·3	64·6	14·2	52·6	110	372
9	456	372	103·5	256·5	81	248
Totals or means	2360	2704	886	2515	116 ± 28	266 ± 78

two columns show a much greater advantage to the " raised " impinger than did the laboratory work (Table 2). In the open air the " raised " impinger recovered nearly three times as much *S. marcescens* as the Porton impinger. The totals at the foot of cols. 2 to 5 indicate that the " raised " impinger is again recovering all the *S. marcescens* sprayed while the Porton impinger kills about two-thirds of this organism.

We attribute this marked difference between the laboratory and open-air work to the cells being in a more sensitive state when sampled in the open, where they have been subjected to the rigours of airborne suspension for a much longer period than in the Henderson apparatus and probably in less congenial conditions. They are therefore more readily killed by the violent treatment of the Porton impinger. The difference in particle size between the laboratory and open-air work (ca. 98% of single cells in the laboratory aerosol, clusters up to 5μ in the open-air aerosol) may also have some bearing on the difference in results, though if this is so the reason is obscure.

The ratios in the last column of Table 9 show rather more variation from test to test than did the laboratory work but this is to be expected because of the lack of control of variables in field work in general compared with laboratory work.

Discussion

The work shows that sonic-velocity impingement, as a means of sampling viable airborne bacteria, is too violent for the more sensitive types of cell. A system operating under liquid with a velocity at the point of impingement not exceeding about 300 m.p.h. is sufficient to trap virtually all individual airborne bacterial cells and no loss of viability can then be shown for the sensitive vegetative cells we have tested. *Serratia marcescens*, which was used in most of our tests, is one of the most sensitive of organisms to adverse treatment. There seems to be no reason why the best types of impinger selected by its use should not also be superior with other sensitive organisms. The reservation must be made that owing to the great inherent variability of living matter, our results will not necessarily be quantitatively reproducible with other strains or types of micro-organism. Also it is possible that cells which have been greatly weakened by prolonged exposure to the airborne state might be unable to withstand even very gentle impingement.

All our work was done with impingers operating at about 11 litres/min. While it seems reasonable that the results should apply to other flow rates, some work by Rosebury (1947) suggests that sonic velocity impingement at 2·5 l/min. gives superior viable recovery to similar impingement at 11 l/min.

Of the various types of impinger tested the sub-critical type seems to be of the highest general merit, for reasons already enumerated. A critical orifice can be incorporated into the outlet tube to make a constant flow system. Effectively all the viable cells which enter the jet of the sub-critical impinger may be recovered unchanged from the impinger fluid.

The so-called Shipe and " raised " impingers, which embody a sonic velocity critical jet with the point of impingement at about 3 cm. from the jet, give equally high performances and the most suitable one of the three types to use is largely a matter of choice. Other impinger types tested were inferior in various degrees.

It is unlikely that the depth of liquid in an impinger is in any way critical provided that it is sufficient to ensure that the air-jet entrains and constantly recirculates the liquid. This process washes impinged particles from the base of the flask and suspends them in the liquid. The liquid barriers presented to the escaping air by the disturbed liquid near the jet must play a part in increasing the filtration efficiency.

It is emphasized that errors due to the inefficient intake into a sampler of the larger aerosol particles with high inertia may completely swamp impingement losses. Comparative tests between different sampling systems must be carefully designed with this in mind.

Summary

The unique features of the liquid impinger as a viable aerosol sampler are described.

Sonic velocity impingement is shown to have a lethal effect on the more sensitive types of bacterial cell.

Tests on various types of impinger indicated an optimum impingement velocity of roughly 300 m.p.h. Below this figure impingement efficiency for small particles falls off, while above it lethal effects start.

Three types of impinger are shown to have high efficiency for the organisms used. Other types, including one hitherto standard, are less satisfactory.

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The Range of Vision Permitted by Protective Goggles

BY

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In her review of ocular injuries and hazards at the British Occupational Hygiene Conference on Protective Equipment, Dr. Campbell called attention to some of the reasons why goggles are not used. "... many goggles have been devised—but so many steam up, restrict the field of vision and add so much to the discomfort of the workman that he will have none of them except in the processes for which he is legally obliged to wear them" (Campbell, 1956; Davies, 1956). The purpose of this note is to call attention to one of these factors—restriction of the field of vision—and to put forward a simple method of testing it.

When current types of goggles are examined it is found that there are two kinds of restriction of vision. The first and most obvious one is the limitation of peripheral vision due to opaque projections at the outer margins of the eyepieces. The less obvious but probably equally important limitation is that of binocular vision caused by opaque projections on the nasal edges of the eyepieces. Normally the limits of vision when eye movements are permitted are determined by the anatomical contours of the orbital region. The limiting structures are superiorly the eyebrows and laterally and inferiorly the tissues covering the orbital margin. Medially the tissues of the nose limit the vision of each eye and hence the degree of overlap of the visual fields available for binocular vision. In the laboratory, the exact extent of these fields can be plotted on a perimeter. Usually for ophthalmic purposes the peripheral vision is explored with the eye directed forwards, but when considering these measurements in relation to the occupational use of goggles, it is more appropriate to allow the eyes to move freely. The angular range so estimated is similar to that obtained with the eyes fixed, but measurements are easier since the test object can be seen more clearly. Precise measurements vary with different individuals, but normally an angle of rather more than 180° can be swept if both eyes are used together. Of this range the overlap permitting binocular vision is about 100° in the horizontal plane. If similar tests are made with the subject wearing standard goggles as supplied for industrial use, the restriction of vision becomes apparent. As an example, observations with a standard type of goggle intended primarily for welding processes show restriction of total lateral fields to 70° and of the binocular field to 40°. The mechanism of this limitation is indicated in Fig. 1, from which it will be clear that any opaque structure encroaching upon the "beaten field" of the line of sight restricts vision. It may be objected that this is inevitable if the lens is to be adapted to the contours of the face. That this is not so can be seen from the diagram since projections in the region beyond the edge of the beaten field need not cause any restriction of vision. Since little, if any such area is available in the nasal region, it follows that projections in the region of the bridge of the nose will usually limit the binocular field. The simplest solution of this problem is to have a one-piece lens which extends beyond the beaten field. Ideally such a lens needs to be curved in two planes, like many modern car windscreens, so as to avoid any restriction of the peripheral field. A number of commercial goggles have been designed with these principles in mind, and it is a matter of technical development for suitable lenses to be produced in this shape for the varying hazards for which goggles are required.

Since measurements by perimetry are unlikely to be available in most factories, the following simple test is suggested by which the effect of any particular type of goggle on a workman's range of vision can be assessed. The test can be conveniently performed in the corner of a well-lit room. From the corner (*C*) a distance of

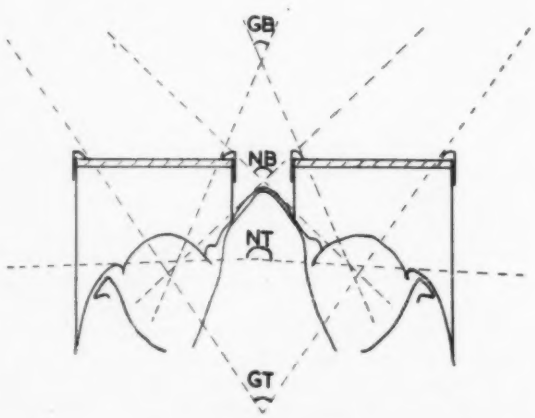

FIG. 1.—Diagrammatic horizontal section through the orbits, showing normal limits of lateral and binocular visual fields and the effect of goggles.

Angle N T. Normal total range
" N B. Normal binocular range
" G T. Total range with goggles
" G B. Binocular range with goggles

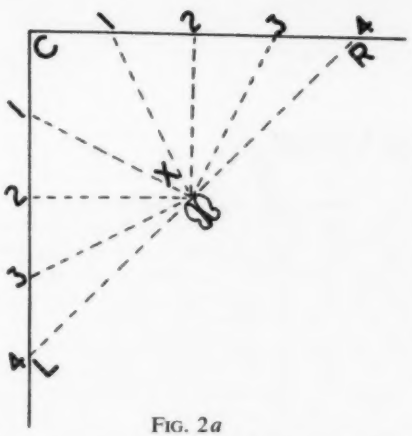

FIG. 2*a*

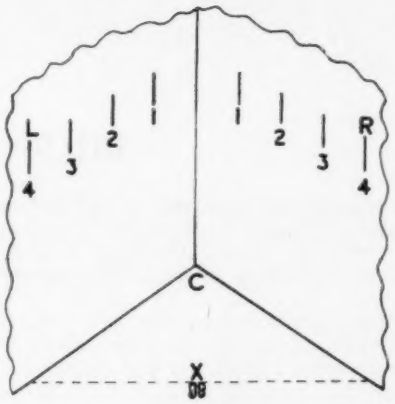

FIG. 2*b*

FIG. 2 (*a* and *b*).—Corner of room set out for test of range of vision permitted by goggles. (*a*) Plan. (*b*) General view.

8 ft. is marked along each of the two walls at a height of about 5 ft. (*R*, *L*, Fig. 2a and b). *CR* and *CL* are marked in quarters at 1, 2, 3, and 4. The marks may conveniently be vertical strips of adhesive paper. The position for standing (*X*) is marked on the floor midway between *R* and *L*. The angles subtended to the subject are: 1-*X*-1 37°; 2-*X*-2 90°; 3-*X*-3 143°; 4-*X*-4 180°.

A normal person standing at *X* and facing the corner, *C*, should see marks *R*4 and *L*4 when allowing the eyes to move. This corresponds to a total lateral range of 180° +. With the right eye occluded the mark *R*2 will probably be seen with the left eye; correspondingly with the left eye occluded, mark *L*2 will be seen with the right eye. This corresponds to a binocular range of 90° +. With many goggles it will be found that even *R*2 and *L*2 cannot be seen with lateral vision (<90°), and that the binocular overlap lies only between *R*1 and *L*1 (37°). (Further intermediate marks may be made to allow more detailed comparisons; alternatively the marks may be rearranged to give direct readings in degrees, *e.g.*, distances of 1 ft. 1 in. and 2 ft. 3¾ in. laid off on both sides of *R*2 and *L*2 will give the series 30°, 60°, 90°, 120°, and 180°. A further refinement is to make a vertical series of marks at *R*2 or *L*2 to measure the permitted vertical range of vision.)

Many workmen who would benefit from eye protection by goggles work in shops where people and materials move about. Without goggles these men are aware of objects moving in the peripheral fields of vision, and normally hearing and sight combine to make sense of happenings in the vicinity. In this way the worker is warned of potential dangers, but if the range of vision is limited by goggles to half or less, the worker is at a disadvantage. His continuing awareness of the potential dangers in the environment is curtailed, and objects to the side can only be seen after turning the head. It may be objected that there would be no advantage for welders' goggles with their low transmission of light to admit a wider field, since other objects are not sufficiently illuminated to be seen. While this may be true for the particular case of protection against intense light, this pattern of goggle is frequently used for other purposes, and many will be found fitted with transparent lenses. It was because of this widespread use of the welder's goggle for general purposes that it has been taken as an example, but the same considerations can equally be applied to other patterns. In the last few years there has been a welcome development of designs which overcome many of these criticisms, but there is still room for their more general use and for other models to be developed which will meet the requirements of all occupations where the eyes are at risk.

Summary

Attention is drawn to the limitation of peripheral and binocular fields of vision by many industrial goggles.

A simple test of the permitted range of vision is described.

Greater use of wide-angle goggles is recommended where suitable patterns are available. Further development is needed of designs appropriate for all circumstances.

This work follows a suggestion by Professor J. R. Squire, Leith Professor of Experimental Pathology in the University of Birmingham, who was responsible for war-time operational research on a similar problem.

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BOOK REVIEW

Reactions of Mines-Rescue Personnel to Work in Hot Environments. By A. R. Lind, J. S. Weiner, R. F. Hellon, R. M. Jones, and D. C. Fraser. (Pp. 68.) London: National Coal Board (Medical Research Memorandum No. 1).

In recent years various physiologists have studied man's tolerance of heat, but they have generally been concerned with the ability to withstand heat for considerable periods, *e.g.*, for a working spell of four hours or for a full industrial shift. When men must work in such great heat that the body cannot maintain thermal equilibrium, as happens during mines-rescue operations, it is important to know for how long they should be expected to work in conditions of given severity. Hitherto the only relevant information has been that provided a few years ago by Roantree from experience with mine fires at the Kolar Gold Field in India.

In this memorandum Lind and his colleagues describe experiments carried out by them for the National Coal Board. The main series of experiments were done in Oxford and in Doncaster, but the results of further experiments made at the Institute of Aviation Medicine, Farnborough, are included.

The experimental subjects were 36 miners, half of whom were aged 19 to 31 years and half 39 to 45 years, and the members of the two age-groups were equally matched as regards stature and body weight. In each group one-third of the men were accustomed to severe underground work, one-third were deputies, and the rest were described as " mixed " workers. Half had been trained in the use of the " proto " breathing apparatus, while the other half were accustomed to the " aerophor " apparatus. During experiments each man wore the apparatus to which he was accustomed.

In the Oxford experiments the intrinsic individual variations in the subjects were measured, the reactions of the men in the two age groups, without the complication of the wearing of apparatus, were compared, and the experiments also served to ensure that none of the men would be exposed to unwarranted danger in the later Doncaster experiments. The work routine in Oxford comprised alternating spells of resting and step-climbing, so that over the experimental period the average energy cost was 111 Kcal./m.^{2}/hr.

In the Doncaster experiments the work routine was designed to represent a mines rescue task. It included a spell of walking and carrying a 50-lb. sandbag, and another spell of building a sandbag stopping, so that over the 65 minutes of the test the rate of energy expenditure averaged 200 Kcal./m.^{2}/hr.

In the first series this work routine was carried out in atmospheres saturated with water vapour at temperatures ranging from 85 to 100° F. In the second, with the same routine, the atmosphere was relatively dry. In three of the four standard environments the dry-bulb temperature was 120° F. and the wet-bulb temperature was 79°, 85°, or 94° F., and in the fourth the dry-bulb temperature was 100° and the wet-bulb temperature 88° F.

From consideration of the periods over which the men could tolerate the various degrees of heat, and from the physiological reactions observed, charts were prepared showing, for the various environmental conditions, the exposure times which it was thought would be safe for all mines-rescue personnel. In considering the unsaturated environments the effective temperature scale was not regarded as reliable for estimating equivalent environments, and instead the figure given by the expression 0·85w + 0·15d, where w and d represent the wet-bulb and the dry-bulb temperatures respectively, was used. In the experiments the men were exposed to an effective air speed of about 150 feet per minute, and tentative corrections are suggested for air speeds below 100 or above 200 feet per minute. It is emphasized that the tolerance times shown on the charts apply only to men engaged in operations in which the work is of a similar nature to that performed during the tests. The vigilance tests led to similar conclusions as to the time over which men could perform rescue tasks in saturated environments before they showed obvious signs of deterioration.

The tolerance times did not appear to be affected by age, and it is concluded that for short-term exposures an upper age limit of 45 is reasonable. The men of the three occupational groups reacted similarly so that there appears to be no particular advantage or disadvantage associated with any particular type of occupation.

In an appendix there is a reproduction of an information bulletin on precautions to be taken when rescue personnel operate in hot and humid atmospheres which is based on the conclusions drawn from the work described in the memorandum. It includes tables showing the maximum safe periods for work under specified conditions of temperature and humidity, separate tables being given for each of the two types of breathing apparatus used.

The work described in this memorandum is of considerable interest from the standpoint of climatic physiology, and it is of great importance to the mining industry. From Appendix II it is evident that no time has been lost in making available the results of the research to those who may have to apply them. The memorandum is nicely produced, but it is regrettable that insufficient care seems to have been given to the checking of proofs. In a list of references on page 49 the names of three authors are spelt incorrectly, and the name of one of the authors of the Memorandum is spelt in one way on the title page and in another at the beginning of Appendix I.

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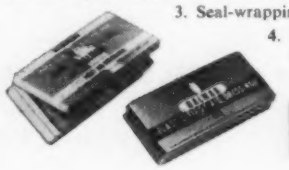

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